SOIL AND WATER CONSERVATION IN THE PUNJAB

By

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INDIAN FOREST SERVICE

With a Foreword by

SIR EVAN M. JENKINS, K.C.I.E., C.S.I.

Governor of the Punjab.

To my Indian Colleagues
whose task it is to turn this soil
conversation into soil conservation.

"They that shall be of thee shall build the old waste places; thou shalt raise up the foundations of many generations; and thou shalt be called, The repairer of the breach, the restorer of paths to dwell in."

Isaiah, 58, 12.

SUMMARY.

This manual attempts to lay down the details of practical field work in the various phases of afforestation of catchments, reclamation of torrent beds and waste land, and the control of run-off from cultivation. In order to show the relationship of erosion control with flood-reduction, a detailed analysis has been made of erosional processes by water and wind as occurring in the Punjab, and the extent to which both are responsible for the destruction of cultivable land and for loss of fertility in land still under cultivation. The steps by which these processes of destruction and desiccation can be reversed are detailed, emphasising water conservation as an essential step in the fuller use of the land.

BARNES COURT,
SIMLA.

FOREWORD.

This Manual of Soil and Water Conservation is intended primarily for the use of officials concerned with land management in the Punjab. Its author, Dr. R.M. Gorrie, is an expert on this subject and has assembled in a compact and simple form the results of many years of research and experience in the Punjab and elsewhere.

Hitherto erosion and desiccation have been intensively studied only in the districts in which their evil effects are most apparent. In those districts considerable progress has been made with preventive and remedial measures. It is now clear that no boundaries can be set to the work, and that throughout the Punjab we must observe and endeavour to deal with soil damage and deterioration, however slight they may seem to be at the early stages.

Knowledge must pass from the officials to the great mass of Punjabi farmers, many of whom are already interested. The Forest Department must take the lead; but all Departments concerned with rural affairs - and particularly the Revenue and Cooperative Departments and the Department of Agriculture - should see that their officials have some knowledge of general principles, and are able to advise upon them and to judge where more expert advice is needed.

The Manual should be of the greatest value to the Punjab, and I wish it all possible success.

Governor of the Punjab.

1st September
1946.

CONTENTS.

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List of Illustrations, Maps and Diagrams.

Chapter I.

EROSIONAL PROCESSES.

"Think of Palestine, Persia and Mesopotamia, and show me a nation that has been devastated by war that has not been able to rehabilitate itself, if only the country in which it lived was well watered and productive. But where is the nation devastated by the desert that has been able, or ever will be able, to rehabilitate itself? Instead of talking of national protection by means of army and navy, we should talk of national protection tion by means of forest, army and navy." (Maxwell).

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1\. 1. *Erosion Defined.*—The soil is the world's greatest resource. Its top layer, usually of only 7 or 8 inches depth, is the principal feeding ground of agricultural crops, but unfortunately this top soil is very easily damaged and removed by both wind and water. Its best defence is a thick cover of protective and permanent vegetation, but in order to grow agricultural crops this vegetation must necessarily be removed, and so erosion occurs.

Soil erosion can best be described as the theft of soil by the elements, and is the removal of soil particles either singly or in mass. It may be due to wind or water action, or a combination of both may occur. Wind erosion whips up soil from flat surfaces and may cause accumulations of sand into dunes but seldom causes any deep cutting. Water erosion on the other hand starts with surface movement of particles down the slope but often may persist until deep gullies are cut in the subsoil and underlying strata. The subsoil differs from the top soil; although its mineral constituents will usually be the same they are not in a form which is directly available to the plant because of the absence of organic matter and of soil bacteria. In hot and arid climates there is not usually that marked difference between the soil and the sub-soil which is apparent in humid and temperate zones.

1. 2. All erosion can be analysed into three parts of one process of movement, and these are: (1) entrainment or picking up, (2) transportation or moving from one spot to another, (3) deposition or dumping at the next spot. This should be kept in mind when thinking either of vast geological changes or of the behaviour of one grain of soil being washed across a field.

1. 3. *Normal Geological Erosion.*—The destruction of the land surface by means of wind and water action has always been a natural process even before man existed on the earth. Most of the great rock groups known as sedimentary have been formed by the breaking down of the parent rock into sand and clay by climatic agents, thence to be river-borne as silt and redeposited elsewhere in lakes and on ocean beds in layers which subsequently become the stratification of the resultant rock. This process has been going on since first a land surface emerged from the sea. The amount of erosion which can be expected to take place as an inevitable and natural process is considerable and it is beyond the powers of mankind to control or prohibit this process, though by his interference with nature's plant cover, it is obvious that man's actions have speeded up the process.

1. 4. *Accelerated Erosion.*—We know that man and his domestic animals have increased the pace of erosion, but it oversimplifies the problem if it is considered merely as a change in the pace of the process. What Lowdermilk has called the "geologic norm of erosion" includes a mental picture of all the land-building and rock forming processes in nature (W.C. Lowdermilk in *Trans. Amer. Geophys. Union*, 1934). The change from the geological normal to the accelerated erosion of today is more than a simple acceleration. In the natural geologic norm, streams carved their channels just the same but the percentage of permanent streams was undoubtedly higher; everywhere except in arid areas forests and grass-lands were extensive and contributed to a stable water regime with many permanent springs and a steady underground water-table. Once this stability has been upset by destruction of the natural plant cover and by gullying, it is not easy to replace.

1. 5. The presence of forests on steep slopes under the geologic norm probably gave deeper penetration of humic acids and thus greater depths of rock disintegrated, to be removed as fine silt during movements of the earth's surface or in mass movement of soil down the slope by a slow creep. The present day equivalent is of a denuded slope which, if of soft rock, con-

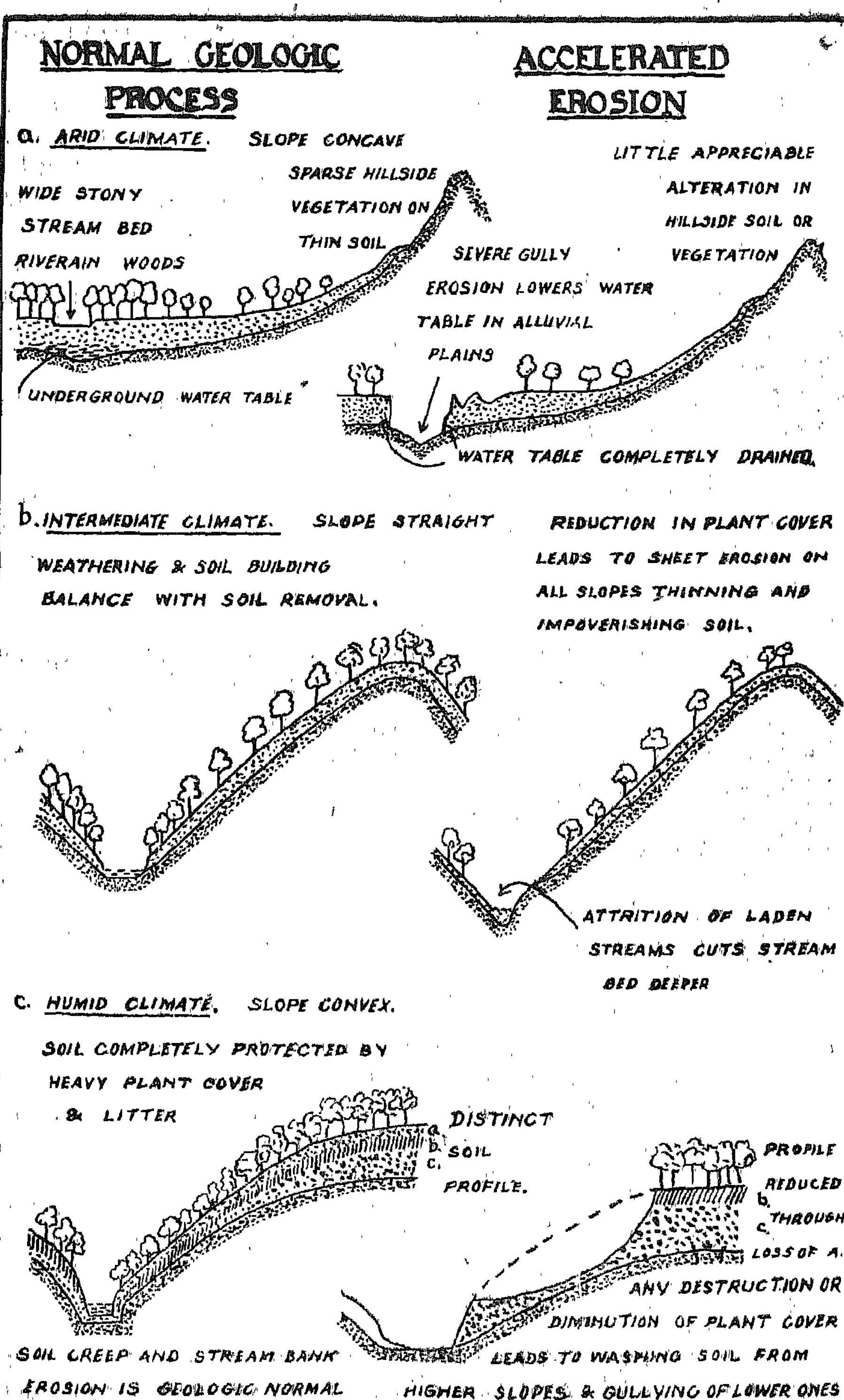


Fig. I. CHARACTERISTIC SLOPE PROFILES

tinues to be destroyed by ravines or gullies, or, if of hard rock resistant to ordinary weathering, is likely to remain without any soil cover at all for centuries.

1. 6. Detailed geological studies by Kirk Bryan in the arid Rio Grande valley and by C. F. S. Sharpe and others in the deep, soft, and easily eroded soils of the Piedmont plateau in the south-eastern U. S. A. bear out facts which are also obvious in our own Siwaliks, namely that catastrophic erosion cycles were frequent in geological times and can therefore take place without man's assistance and that periods of excessive cutting can by a change in climate or streamflow be halted and replaced by stable periods.

1. 7. *Mature and Immature Soils.*—The soil consists of inorganic (mineral) and organic (plant & animal) substances; the former have never formed part of living matter but are particles of the parent rock disintegrated and decomposed under the action of natural agencies or deposited by the flow of water or by the force of wind. The organic substances in the soil have, on the other hand, at some time or other formed part of some living organism, either animal or vegetable. The soil also consists of soil water, a dilute solution of carbonic acid containing small quantities of every soluble soil constituent.

In nature, where crops are not harvested, mineral plant food is used by plants over and over again. This dead vegetation is decomposed and mixed with the soil by the activity of various living soil organisms when it forms HUMUS. The plant during its life not only takes in food from the soil but also from the air so that, under natural conditions when crops are not harvested, the residue of the dead plant returns more to the soil than the living plant took from it. It is this addition to the soil which is the source of energy required by the various soil organisms upon the presence of which soil fertility so largely depends.

A geologically mature soil is usually deep and rich and shows a number of colour gradations from a top-soil rich in humus matter and in fully decomposed mineral particles. Its subsoil shows many stages of this decomposition above the parent rock, but the whole profile from above downwards shows only a very gradual blending from one stage into another. Man's use of such soil either for plough land or for grazing sooner or later destroys this gentle graduation, and the valuable top-soil is ploughed out or washed away.

1. 8. Climate has also always been at work in regional variations. With good rainfall and a heavy plant cover deep soil profiles can form, but in arid regions this does not occur,

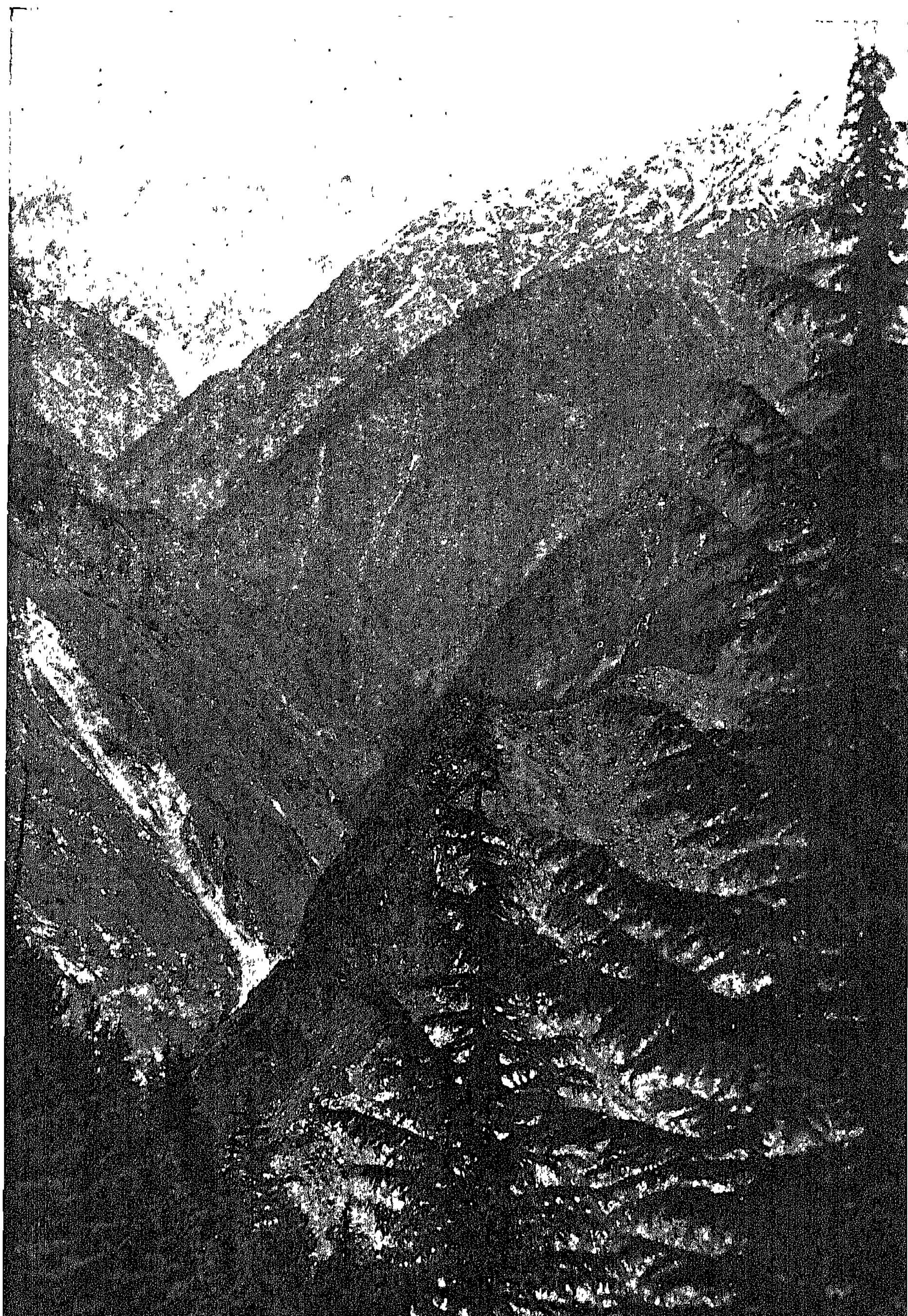


PLATE 2.

Land-slides in the arid Sutlej; The nearer slopes are scarred with frequent landslips along the main Sutlej valley and the outer Bhabba Nal. The higher parts of the Bhabba Nal in the middle distance are better covered with forest and so show less obvious erosion.—Para. 1,8.

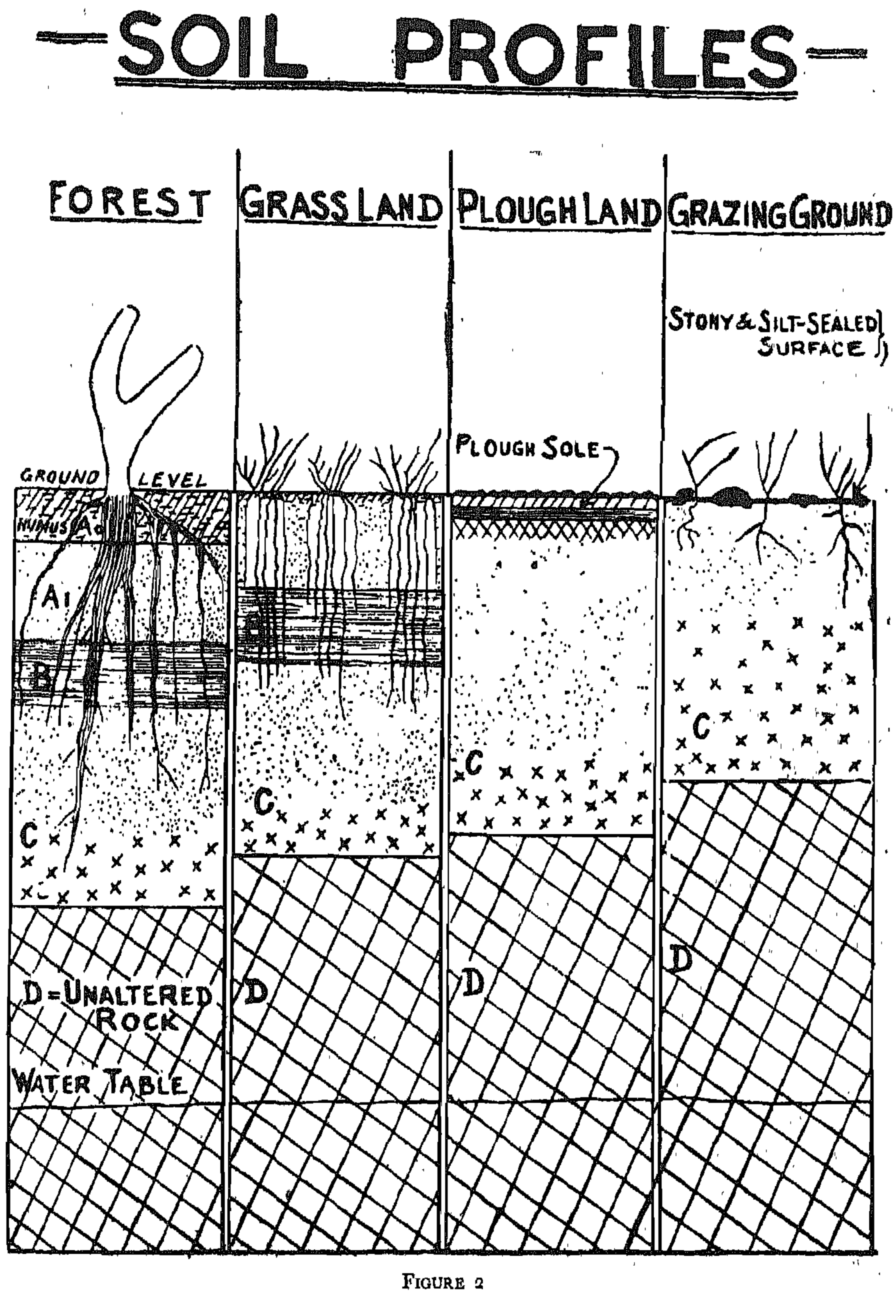


FIGURE 2

and without a mantle of vegetation, soil cannot accumulate on steep slopes. Mature soils in humid countries show a great capacity for absorption, largely because climate works through the plant cover as a means of water conservation under undisturbed natural conditions. In regions too arid to produce an adequate plant cover however the features of erosion, namely

wind erosion, sheet washing of slopes, and gullying and ravining of vulnerable uplands are common to the geologic norm, largely because of the absence of that cover. (Plate 2).

1. 9. *The Dynamics of Erosion by Water.*—Webster's Dictionary defines "dynamics" as a study "treating of the motion of bodies and of the action of forces in producing or changing their motion", hence the use of the term here is appropriate.

The shaping of the land surface by the forces of nature is a factor in geology which has been effective ever since the land first appeared above the sea. Why then is it that erosion has become such a pressing modern problem? There is and has always been a geologic normal of erosion, in which slopes even when covered with forest and grass-land, or rather because of them, have been altered by the building up of deep mature soils. Protection by plant cover gives time and scope for soil-forming processes to go on. Without vegetation's aid to weathering and to nature's processes of building up complex chemical and biological reactions, mature soils cannot develop. In humid areas deep soil profiles are common, because the normal plant cover and litter are available to establish them. In arid areas, on the other hand, the normal plant cover is so thin that it fails to form a complete mantle, with the consequence that one or more types of erosion, namely sheet-wash, gullying, or wind erosion, have probably always been in evidence. Without a plant cover, no soil can lodge on any slope steeper than the angle of repose for the type, and even from gentler slopes the products of weathering will blow or wash away soon after they are formed.

1. 10. If this happens under the geologic norm, what difference does man's presence make to the pace of erosion? It is in trying to find the correct answer to this question for any one given set of local conditions while actually carrying out the detailed field work of soil conservation that we can "separate the wood from the trees" and evaluate the gains of such work.

The chief effect is that through the destruction of the natural plant cover throughout much of the medium humid climatic belts, these same features of gullying and wind erosion are being extended far beyond the regions of the natural desert and arid zone to which they would have been confined. But the transition from the geologic norm to man-made erosion is not only one of pace and extent in hastening and extending the simple processes of geological attrition. By removing the natural plant cover, man has destroyed the somewhat delicate balance which nature has previously struck between plants and animals

and the soil, and has brought in all of nature's destructive forces to abet his own. Run-off is enormously increased, both in rate and total amount, so that streams become irregular, their load of detritus moves more erratically, peak floods reach higher crests, and drought periods between become more severe and more marked.

1. 11. *Rain-drop Erosion.*—Each raindrop as it falls is responsible for some damage to the texture of the soil. In the force of its fall it tends to smash up the crumb structure which disintegrates into small particles from which the valuable colloidal material is the first to join the drainage movement. The pore openings of the surface reduced by the breakdown of these aggregated crumbs are clogged by the infiltration of other silt particles. The raindrop falling on a hillside tends to splash mud further downhill than it does uphill and actual measurements show that on a 18% slope 3 parts of soil splash moved downhill for every one moving uphill. The damage due to splashing depends upon the size and velocity of each raindrop, the intensity of the fall, and the strength and direction of the wind. The loss from sheet erosion depends on the other hand on the hydraulic efficiency of the mud mixture in its move downhill and the resistance against disintegration which varies with the character of the soil (W. D. Ellison. Studies of Rainfall Erosion; *Ag. Eng.*, April, 1944). Erosion losses measured in terms of the concentration of mud in the run-off water increase by as much as 1,200% with increase in size of individual raindrops. (J. O. Laws. Recent studies in Raindrops and Erosion; *Ag. Eng.*, November, 1940). As the size of the drop was increased in Laws' experiments the rate of infiltration of water into the soil decreased by as much as 70%. The inference from all this is of course to emphasize the need for keeping the soil covered either with a dense mass of low growing herbs and grass, or with a mulch of cut grass or crop residues, or even with an "erosion pavement" of stones rather than have the soil exposed. (For erosion pavement see para. 5. 29).

1. 12. *Sheet Erosion.*—On ploughed land the periodic working of the surface soil helps materially to prevent any concentration of the erosion so that soil movement is uniform and affects the whole of the surface by sheet erosion. The moving soil itself exerts a scouring action and so minute rills or channels are formed, but with each ploughing these are erased and the irregularities of the surface are equalised. When ploughing is stopped then this equalising process ceases and the rills deepen into gullies. The loss of plant nutrients by sheet erosion varies,

according to Lipman, from 3 to 31 times the amount of the mineral elements extracted by harvested crops. (*New Jersey Ag. Expt. Stn. Bull.* 607, 1936). Heavily grazed land, where misuse has driven out the grass and left seasonal weed crops or pulverised bare soil, also suffers from sheet erosion but this develops more rapidly into gullying because the cattle paths themselves form incipient gullies. Sheet erosion is also encouraged by frost which leaves bare soil surfaces in a puffy and easily erodded condition; the cumulative damage by frost and thaw on fallow and ploughed slopes is a serious factor all through the Himalayan cultivation belt.

1. 13. The extent to which sheet erosion has taken place is often indicated by small pillars of residual soil capped by a single pebble or flat stone, the presence of which has preserved the soil immediately protected by it. It is also indicated by the fact that bushes and trees are on silts, i.e., their roots are exposed in a sort of inverted umbrella shape indicating the depth of soil which has been lost since the plant germinated at the original surface level. This is well seen in the Kangra tea gardens in some of which every tea bush is of this shape.

1. 14. Man-made erosion is probably at its worst in land which man himself has abandoned, as nature seems to be incapable of re-establishing any sort of quick protective balance on land where the crumb structure has been destroyed and the surface soil reduced to an amorphous powder, and it is in such land that gullies and ravines are forming at a truly alarming rate. In ordinary agricultural tillage, periodic reworking of the soil removes the early stages of rills or "shoe string" or "finger" channelling; some soil is lost, but cultivation tends to equalise the newly formed irregularities and iron out incipient gullies. But when land is abandoned this ironing out ceases as a remedial measure and these rills and small damages persist and develop rapidly into major gullies.

1. 15. At this stage the dynamics of erosion become obvious in the tiny columns of soil which appear to rise wherever a pebble or a plant root or even a scab of lichen serves to shield the soil immediately below it. Actually of course this soil has not risen; all exposed soil in its immediate neighbourhood has been washed away, leaving this protected cylinder in position when all else has gone from around it.

As the rills deepen, stones left behind by the washing away of the finer soil components tend to migrate more slowly and accumulate in the bottom of each rill. This particular channel becomes stone-paved and so becomes temporarily more resistant

to further wash, so the rill moves sideways, cutting laterally into undisturbed and more vulnerable soil.] Only exceptionally heavy rain or ploughing, or undercutting by enlarging gullies will shift the pebble pavement from those earlier channels.

1. 16. *Gullying.*—The history of gullies in the soft American Piedmont soil, which is very similar in its erodibility to the deep sandy loams of the Jhelum and Rawalpindi upland plateaux, has been worked out in detail and helps us to understand our own local problems, when the soil is underlain by deep beds of rotten or unconsolidated rock such as Siwalik sandstone, or the red marl and shales of the Salt Range. The first stage is when the rills deepen and start to destroy the A and B horizons of the soil by down-cutting, the cutting power being provided by the surface run-off concentrating in the rills whose sides and bottom are being attacked by the water-borne soil. Subsequent stages are when the soil thus hollowed out collapses in pot-holes as deep as the B layer. If there is any hard pan or layer here it will protect the rotten rock below, but if there is none, the C horizon may be even more vulnerable and collapse in vertical slumping. The terms A, B, & C horizons are commonly used to demarcate the changes in colour and character of any vertically exposed section of soil. The 'A' horizon is the "top-soil", the 'B' horizon is the subsoil of partially matured but mostly mineral soil without humus, and the 'C' horizon is only partially rotted rock.

1. 17. *Stages of Gullying.*—As the gully is our arch-enemy, or rather the enemy's arch-weapon of destruction, a detailed analysis of its development is called for. There are several fairly easily recognised stages of development, though some of these may be "telescoped" into one another and happen simultaneously. (Ref: *Tr. Am. Geoph. Un.*, 1941, C. F. Stewart Sharpe).

1. 18. [In the first stage, sheet wash begins to merge into the formation of rills or finger gullies of only a very few inches depth,] as has already been described above, and the extent to which it can be prevented or controlled artificially is dealt with later. We are at the moment concerned with the mechanics of the various stages. The length of time this stage lasts depends upon many factors, but chief among them are the following:—

(i) the condition of the soil. When the humus content is high the soil is more absorptive and less easily destroyed; it is because of this that emphasis is placed on the need for frequent application of farmyard manure

rather than artificial or chemical dressings. A good crumb structure is the best defence.

(ii) the maturity of the soil as marked by any well developed profile or changes in colour, usually defines layers of more or less resistance. In immature soils or where erosion has already destroyed all traces of layering and has left a uniform subsoil, the whole of this is liable to become eroded down to the rock without offering any levels of resistance.

(iii) the presence of any pan or induration near the surface which may serve as a tray; if this is impervious it will exaggerate the rate of sheet wash so that all the soil on top of it is removed quickly, but it forms a cap to preserve everything below it.

(iv) the action of frost upon moisture-laden soils is most peculiar and will be discussed separately in para. 5.16.

1. 19. The next stage in gully formation is that of vertical cutting through the underlying strata wherever the pattern of small drainage channels combines to form a major one capable of deeper destruction. This is the stage at which spectacular damage begins in those soil types where the underlying B horizon or subsoil is more vulnerable than the A one above it. And this is therefore the stage at which remedial measures must be taken up if the expense of reclamation is not to reach very high figures.

1. 20. The third stage is when undercutting by these vertically carved gullies reaches the parent rock. If this consists of very deep layers of rotten and decomposed rock which has lost it cohesion, or if there is no real rock but merely uncompacted sand or pebble beds, as commonly occur to great depths in the Siwaliks and the underlying plains strata associated with them, chasms of very great depth will be formed quickly. This stage is usually marked by pot-holes appearing in exposed channels.

1. 21. The fourth stage is when deep gullies eat backwards uphill behind them, the surface drainage forming a waterfall over the exposed ledge. Where this exposed ledge is part of an indurated crust which resists water action, further horizontal cutting may be arrested for some time but usually the softer strata below this ledge cave in to such an extent that a portion of the indurated ledge is left unsupported and eventually breaks away as a block, when the process is repeated all over again at the new lip.

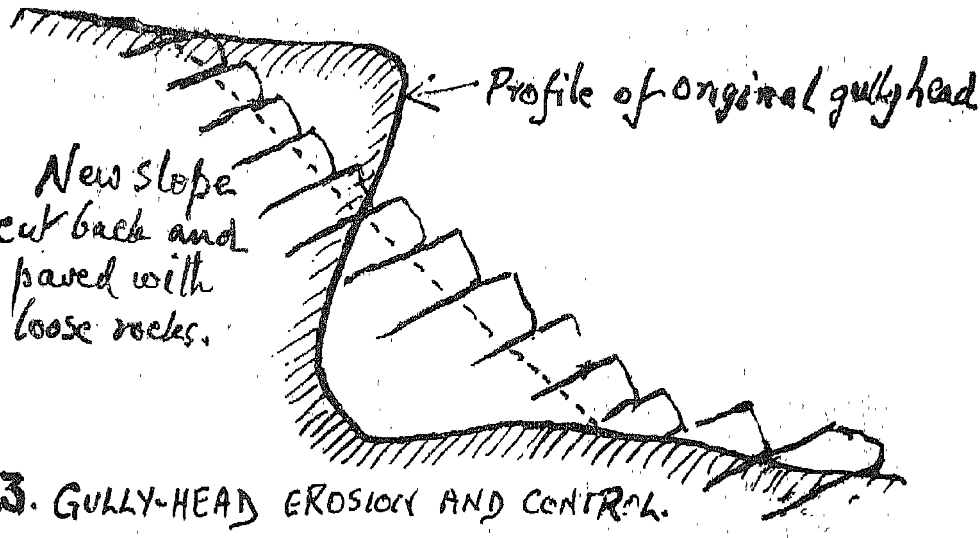


Fig3. GULLY-HEAD EROSION AND CONTROL.

1. 22. The growth of gullies at any of these stages is seldom a uniform matter but is regulated by the type of storm rather than by the total annual rainfall. The slow drizzle of our cold season storms may be continuous enough to soak the soil completely, and so cause the slumping of vertical banks into gentler slopes, but will seldom be intense enough to cause much cutting or backward progress of the gully-head. [Thus winter is the best time of the year for remedial work and planting, rather than in the monsoon when sudden and intense downpours of rain cause very high and suddenly accumulated floods]. It is these intense storms which not only cause the gullies to eat back into the higher ground but also broaden their track of destruction by clearing away all vulnerable material. They may also establish an entirely new cycle of erosion by determining fresh low points in drainage channels down to which the underground water-table level of the surrounding land retreats. An example of this last phenomenon was observed in September 1924 when one of the worst storms ever experienced in the comparatively dry inner ranges of the Himalayas tore out great gashes on the hillsides of Bashahr and Pangi, completely altering the moisture balance of these areas for ever after.

1. 23. *Desiccation.*—Each new cycle of erosion which extends gullying into areas of relatively high rainfall is a feature of man-made erosion, and it is in the world's natural grass-lands with a rainfall of 30 to 60 inches that the pressure of population is causing the worst erosion damage, local examples being the lower slopes of the Punjab Himalayas such as the Ambala and Hoshiarpur Siwaliks, the Kangra Valley and the Murree Hills,

and the outlying low hill ranges such as the Gujrat Pabbi and the Jhelum Salt Range. The desiccation of these low ranges has an ultimate and disastrous effect upon the water-table of the adjoining plains or *doaba* lands, as is clearly seen in the failure of wells in the Ambala and Jullundur plains. Disforestation to make way for unterraced cultivation has increased the violence of the surface flow to such an extent that little percolation or seepage takes place. Now that the streams flow less regularly and their load of debris and silt is carried more fitfully and dumped in an irregular cone of deposition on the plains, floods reach higher crests, but the intervening drought periods last longer. It is thus that the underground water-table is eventually so disturbed that the wells dry up and the remaining forests disappear in face of the increasing local aridity which stops their natural regeneration.

1. 24. *How and where can we reverse these processes?*

Some observers have defined yet another stage in gully development, namely that of healing and stabilisation, which is marked by the shelving of gully walls to an angle of repose, and the return of vegetation to take charge of these slopes, and in some places by the silting of the gully until it is partially refilled with fresh deposits of silt. Such a cycle of cutting and refilling is recognisable in the Piedmont, where it has been described by D. H. Eargle (Ref. *Science*, 1940) but has nowhere been observed in the Punjab uplands, where destruction is much more likely to run the full gamut and finish with a vast plain of sterile sand.

1. 25. On the other hand, the stage of destruction already reached in Hoshiarpur and Ambala Siwaliks and the plains below them formed directly from their destruction in the past, is appreciably nearer to geological balance, and with the easier replacement of the plant cover with the higher eastern rainfall, we ought in the nature of things to be able to put the whole process of destruction into reverse gear more readily in the eastern Siwalik districts of the Punjab than in its western uplands.

The essential differences between these two areas lie in:—

(i) rainfall, the east getting considerably more than the west, on a rough average 46 inches as compared with 18 inches, (see rainfall zones in map at front cover).

(ii) the resultant natural plant cover is therefore easier to preserve or re-create in the east.

(iii) geologically the east is down to plain level or very nearly so for even the steepest Hoshiarpur chos have

a comparatively small drop in level from head to tail, whereas the western uplands have still a great depth to cut through before the feeder streams and torrent beds work down to the base level of the main rivers which they join only a few miles down-stream.

(iv) man's own contribution is also different, for the industrious Jat cultivator of the eastern districts, and the other Hindu and Sikh cultivators, are much less destructive to tree growth than are the Mohammadans of the western districts. The *forest co-operative* movement is well established in the east but hardly begun in the west.

1. 26. We must not, however, be unduly despondent about the prospect of success in the west, and a study of the geological normal of each of our catchments should be of the greatest use in helping us to localise the areas of rapid destruction, where we shall have to redouble our efforts for reclamation. The geological processes are so slow and we have such an effective new weapon in mechanised equipment that we can have some confidence in tackling the very worst ravined uplands.

1. 27. If deterioration of plant-cover gives rise to accelerated run-off which causes floods, then downstream engineering structures may be able temporarily to confine flood-flows and their debris, but they will not lessen flood frequency and height, nor will they keep the soil on the slopes, nor the silt out of stream-channels, reservoirs, canals, and harbours. On the other hand if peak floods are normal and are caused primarily by storms and steep gradients, with the depletion of plant cover playing a minor part or no part at all, then to attempt to develop a control-programme based upon watershed management and plant cover rehabilitation would be futile (R. W. Bailey, *Trans. Am. Geophys., Un.,* 1941).

1. 28. In attempting to analyse the difference between normal and accelerated erosion for any one catchment the vitally important factor is the comparative porosity, or infiltration rate for the absorption of the rain where it falls (a) on the land as now used, and (b) on the same land in the condition it was in before the period of the British raj which has allowed such phenomenal increases in human and animal population. In making such assessments, it must be remembered that properly terraced and watted fields are more efficient in stopping run-off than anything nature can provide in the way of arid zone bunch-grass under any open stand of scrub-jungle trees on appreciable slopes. Also that even at its best, the arid zone plant cover

cannot possibly eliminate damaging floods altogether, although, given fair treatment, it can go a long way in mitigating them. Local differences in the relative performance of adjoining or comparable streams, the characteristics of which are always well known to the local people, should be carefully analysed to see wherein that difference lies, and starting with the main factors of:—

(i) rainfall in amount, intensity and distribution.

(ii) characters of basins, slopes, profile of stream from head to tail.

(iii) soil mantle and plant cover.

Until we get more local data, particularly on rainfall intensity and on the stability of plant-covered slopes, our analysis will be more of a guess than proven scientific reasoning, but every attempt at analysis will bring us nearer the truth.

1. 29. *Erodibility of Soils.*—By physical analysis the soil is split into its component parts according to the size of the soil particles. For convenient reference various grades of particles have been given the following names:—

Over 3 mm.	Stones.
Between 3 mm. and 1 mm. . .	Gravel.
Between 1 mm. and .2 mm. . .	Coarse silt.
Between .2 mm. and .04 mm. .	Fine sand.
Between .04 mm. and .01 mm. .	Coarse sand
Between .01 mm. and .002 mm. .	Fine silt.
Under .002 mm. . . .	Clay.

It is in accordance with the proportion in which these various grades of particles are present that a soil is classified. There are many systems of classification but that most generally used takes account of the quantity of clay present, and is known as Hilgard's classification:—

Very sandy soils . .	0.5 to 3 per cent clay.
Ordinary sandy soils .	3 to 10 per cent clay.
Sandy loams . .	10 to 15 per cent clay.
Clay loams . .	15 to 25 per cent clay.
Clays . . .	25 to 35 per cent clay.
Heavy clays . .	35 per cent clay and over.

1. 30. Such a classification is of practical value to the farmer as most of the mineral elements of plant food held by the soil

are contained in the clay. It will also tell him whether his soil will be *light or heavy to work*. Although a given volume of clay particles is in actual fact lighter in weight than the same volume of sand particles, a clay soil is always heavier to work than a sand soil owing to the characteristic of clay soils of "running together" and forming a conglomerate mass. This feature is obviously linked with their water-holding capacity, and also with capacity to resist erosion. When muddy water first penetrates a soil the moving particles are strained out and lodge in the pore spaces at the surface, thus the openings become choked and further infiltration is interfered with. The laboratory measurement of the rate of water intake of clean water by undisturbed soil samples shows that most soils are fairly absorptive, but once the surface has become sealed by mud which the water itself picks up, further infiltration may stop altogether.

1. 31. Different clays themselves vary enormously in erodibility. Friable but non-plastic, much-weathered clays may be almost immune whereas unweathered plastic clays with a high colloid content (having a high ratio of silica molecules to iron and alumina molecules) are more easily gullied and washed away. Generally speaking soils with the texture of single unprotected grains (as opposed to aggregated groups of grains) are very liable to erosion. Crystalline sand is less easy to move than fine silt by a stream of water, but on the other hand silt is usually associated with enough clay to make some sort of bond or aggregate so that texture alone is not of as much significance as one might expect.

On the other hand soils of low organic matter content all suffer readily from erosion. This is because the water-holding power of the soil depends greatly on the manurial content of the decomposed plants and of any other matter added to the soil. Manures fall into two separate groups, organic and inorganic. The former are substances of animal or vegetable origin, whilst the latter are mineral salts. The latter usually are in a form which is directly assimilated by plants, whilst organic manures have first to be reduced by the action of bacteria or moulds before the nitrogen, potassium and phosphorus which they contain can be used by the plant. Apart from their value as food to the plant, organic manures have another function which is not fulfilled by inorganic manures,—their effect on the texture of the soil. In the absence of organic matter it is practically impossible to obtain a good tilth and, in view of the rapid decomposition and loss of humus which occurs in our drier sub-tropical soils, it is in this respect that organic manures assume an im-

portance not usually apparent in more temperate climates. In all types of *barani* (rain-fed) cultivation, and more particularly in the high hill catchments whence goats have been evicted, there is urgent need for the teaching and practical demonstration of proper manure production by the use of all available sources of plant remains, dung and urine.

1. 32. It may safely be said that in India, inorganic or artificial fertilisers rarely yield economic returns in any way comparable with those obtained from the use of organic manures, nor do they contribute at all to resisting erosion. Animal dung contains those parts of the ration which are not readily digested by the animals' gastric juices, so it follows that if these substances are not readily decomposed within the animal, they will also take long to decompose in the soil. Dung is a slower acting manure than is urine, for it has to be broken down by moulds and bacteria, whereas urine is quickly converted into ammonia, which is readily nitrified. The effect of urine will last only for one crop, whereas dung will have a lesser effect over a longer period, but for hastening a good plant cover or ensuring a good start to tree sowings on already denuded slopes, the application of liquid urine or a dressing of mineral salts is of considerable value. Liquid urine is also of immense value for adding to compost heaps of dead leaves and forest litter, and so building up a more complete plant food.

1. 33. The chemical composition of a soil affects its erodibility directly through its physical properties and indirectly through its effect on plant growth. The most important single chemical factor is the proportion of silica to the iron and alumina, for these three together constitute the plasticity of the soil; the higher the ratio of silica to the "sesquioxides" or iron and alumina, the more plastic it is, so that shrinkage and cracking causes such soils to break down more quickly under constant wetting and drying.

Soils with a good proportion of water-stable aggregates are more resistant, so more force is required before the surface wash can shift them. Sandy clay or limey sand subsoils are easily cut up into grotesque patterns of caving and honeycombing, whereas a deep silt will break off in large blocks even when undercut. Surface cracking in heavy soils is much more extensive in good fields than in poor ones of the same soil type, and these cracks perform a useful function in taking the effect of weathering deeper than it would normally go. (*Nature*, 3-10-42, A. Sreenivasan).

1. 34. *How water is held in the soil.*—Water is present in three different forms:—

(1) there is the very thin coating of water which surrounds each individual soil particle and is called HYGROSCOPIC WATER. The smaller the soil particles, the larger the amount of water held as a coating. It is doubtful whether it is of any value to the plant because it is so firmly held by the soil particles it envelopes, but it undoubtedly has a moderating effect upon soil temperature.

(2) there is the water which after a shower of rain or an irrigation, flows downwards through the soil by the force of gravity. In humid regions after every fall of rain this GRAVITATIONAL WATER finds its way down to the standing water-table, see para. 5.8. (Under arid conditions and where there is no apparent water-table it sinks very gradually through the soil, becoming more dispersed the deeper it goes). It is in this form that water is stored in the soil until required by plants. Cultivation and soil preparation should be directed towards providing a receptive layer so that absorption may be rapid in order to defeat the evaporating effects of sun and wind.

(3) there is the water that is held between the soil crumbs by surface tension, which is the natural attraction which exists between water and nearly all known substances. It may be observed by dipping a stone in water and noting that after withdrawing it, a film of water will adhere to the stone, held by a force greater than the pull of gravity. Water held in this way is termed CAPILLARY WATER and it is upon this water that plants exist during their period of growth. It is important, therefore, to discover under what conditions the maximum amount of capillary water may be held by each soil at the point known as field moisture capacity (see para. 5.8).

1. 35. It will be apparent from the foregoing that the greater the area of the surface of the soil crumbs the greater will be the soil's capacity for holding capillary water. We may imagine a soil crumb of 1' cube in shape. Each side has an area of 12 × 12 square inches, or a total surface area for the cube of 12 × 12 × 6 sq. inches, that is 864 square inches. If we now split this cube

into as many 1 inch cubes as possible we shall have 12 × 12 × 12 one inch cubes each having a surface area of six square inches. We have therefore increased the surface area of the whole to 10368 square inches. We find that the smaller our soil crumbs or the finer our soil texture, the greater will be the soil's capacity for holding capillary water. Thus a clay soil with its smaller grains has a greater capacity for the retention of useful water than a sandy soil.

1. 36. *Causes of loss of soil water.*—Soil water is lost in the following ways:—

(1) by surface run-off which may be prevented or at least controlled by bunding, contour cultivation, and by keeping the soil permeable by proper and timely cultivation.

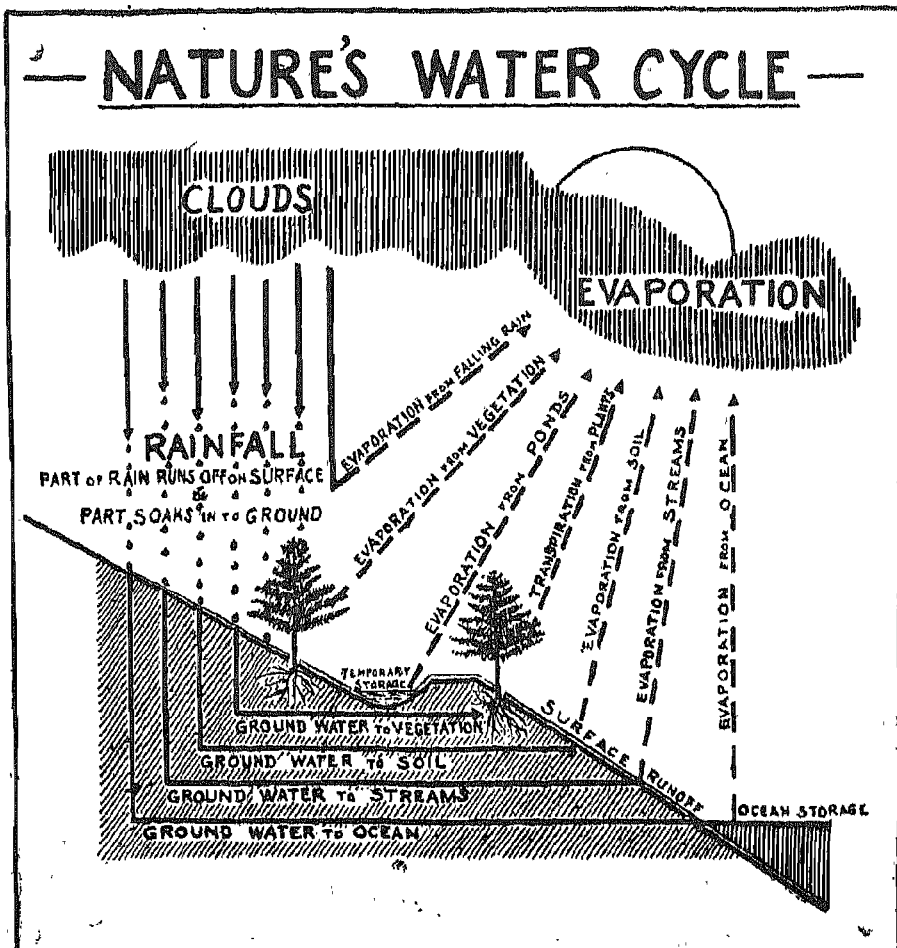


FIGURE 3A

(2) by gravitation. This is not a serious source of loss except in the arid regions where there is no appreciable water-table within any reasonable depth. It is, in any case, impossible to prevent this loss, though by improving the retentive power of the soil by the addition of organic matter and good cultivation it can be minimised by increasing the ratio of capillary water held.

(3) by evaporation, the most serious cause of loss of soil water and fortunately the one over which the farmer has the greatest measure of control. It is only by the right kind of cultivation, carried out at the right time and to the right depth, that evaporation may be controlled (para. 5.5). Capillary soil water has the tendency to distribute itself evenly throughout the soil, up to that soil's field moisture capacity. It follows that unless the farmer provides some form of insulation between his store of soil water and the agencies of evaporation (the sun and the wind) he will soon lose his reserves from immediately below the surface. See under Mulching, para. 5.30.

(4) In addition to these direct causes of loss of soil water there is a further indirect loss due to transpiration by the plants growing in the soil. (see para. 5.7).

Chapter II.

SUMMARY OF CONTROL METHODS.

2. 1. *Up-stream and Down-stream Engineering.*

(i) Up-stream engineering consists of every means by which run-off can be delayed or redistributed at and near the source, and includes:—

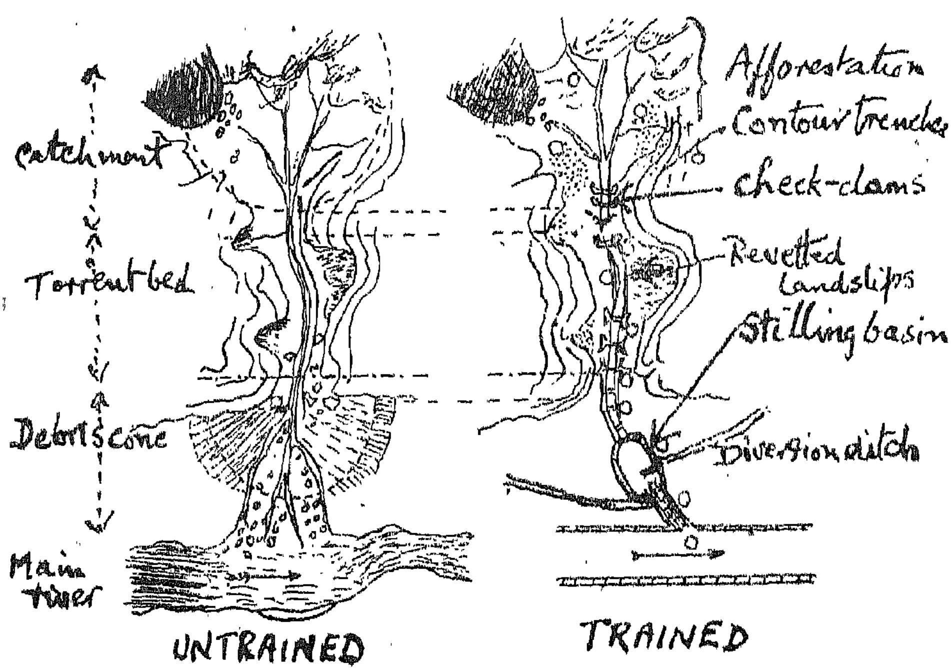
(a) increasing or improving the plant cover.

(b) improving of fields by contouring, and by cultivation practices.

(c) small scale detention structures, including gully plugging of stream origins, contour ridging, water ponds for livestock.

(d) minor dam projects to pond back water within the hill catchment.

Fig. 4. TORRENT TRAINING.



(ii) Down-stream engineering consists of all other attempts to confine or redistribute flood water after it has issued from its confined hill catchment onto the plains below, and includes:—

(a) the canalisation of streams to confine them to a definite bed down which detritus will be carried further down-stream.

(b) the provision of an afforested belt on both banks which can serve as an overflow for the partial disposal of extra heavy floods.

(c) larger engineering structures such as dams, reservoirs, levees, extra flood channels.

2.2. In many countries such as China and America there has been much dispute between the protagonists of these two methods, but is is gradually becoming admitted that they are complementary to each other, and that either by itself is incomplete, particularly when the control of major rivers is being attempted for the development of navigation as well as water-power. On the other hand when we are dealing with Siwalik torrents which disappear into the sands of the plain a few miles from the foot of the hills, the question of major engineering works need hardly be considered except insofar as major storage projects within the hills are contemplated.

2. 3. *Function as a Basis.*—The rest of this book consists of a detailed consideration of control methods. These cannot be fully separated on a basis of plough-land and non-plough-land because these two are in practice inextricably mixed. An attempt has therefore been made to classify them on the basis of *function*.

The use of the terms up-stream and down-stream engineering is helpful in sorting out such a classification but they can in the nature of things only be very roughly applied. Ordinarily up-stream engineering includes waste land management (items 1 to 6) plus all farm practices (items 7 to 25) as well as the minor operations in the heads of torrents (items 26 to 28), while down-stream engineering applies to the rest, items 29 onwards. The use of these terms is in no sense a definition of departmental responsibilities and it will be the duty of the proposed Land Utilisation Board to allocate tasks to the agencies best fitted to do each. (See para. 13. 30).

2.4. *Summary of Erosion Control Methods Classified by Function.*

Function.	Methods.
A. to *improve existing plant cover* on all *unploughed* land	
(i) through grazing control.	1. reduction of surplus cattle.
	2. closures, complete and rotational.
(ii) through village organisations ...	3. partition of shamlat (common) land.
	4. co-operative management of grasslands.
(iii) through forest protection and afforestation.	5. better management of existing forests.
	6. village plantations.
(iv) for wind erosion measures, see under J below.	
B. to build up *soil fertility* in ploughed land.	7. manuring and green manuring.
	8. preserve stubble and crop residues.
	9. consolidation of holdings.
	10. improve tenancy conditions.
C. to *reduce the exposure of bare soil* particularly during monsoon.	11. choice of crops and crop rotations.
	12. strip cropping.
	13. reduce bare fallow.
	14. restrict cultivation of steep slopes.
D. to increase *surface storage and infiltration.*	15. cover crops and mulching.
	16. contour ploughing.
	17. contour ridging & wattbandi.
	18. bench terraces.
E. to increase infiltration into the *deeper layers*	19. subsoiling.
	20. trenching.
	21. basin listing.
F. to prevent run-off gaining a *cumulative velocity.*	
(i) by control of *field drainage.*	22. grassed ditches.
	23. masonry outlets in field bunds.
	24. contour bunds set out with a side slope so that water is led off fields quickly.
	25. live hedges & contoured hedgerows.
(ii) by control of *drainage outside fields.* ...	26. gully plugging & check dams.
	27. reclamation of ravined land.
	28. control of snow melting in high catchments.
G. to divert *excess water* out of natural channels.	29. diversion bunds.
	30. diversion ditches.
	31. deliberate water-spreading by flooding of overflow meadows.
	32. water tanks.
	33. road drainage control & recovery of landslips.
H. to head back *accumulations of water* in the river bed itself.	34. small water-holding bunds in multiple along torrent beds.
	35. major reservoirs.
I. to confine the torrent or river to a *planned channel.*	36. canalising smaller torrents by vegetational control.
	37. river bank consolidation in major streams.
J. to reduce *wind erosion.*	38. fixation of sand dunes.
	39. shelterbelts and wind-breaks.
	40. improve dry-farming practice.

Chapter III.

CONTOURING IN PRINCIPLE AND PRACTICE.

I. *In Principle.*

3. 1. It is important that all soil conservation workers should grasp the essential principle of working along the contour as this is the only sound basis on which surface water can be controlled and stored. "Contouring" is any practice which drives a plough furrow, ridge, or ditch on the level and along the hillside, that is, on the contour. (The ultimate object is the control of soil erosion in areas of high rainfall, and the conservation of all available moisture in areas of low rainfall.) Contouring will pay dividends in the increased yield of every type of crop, whether cereals, commercial plantation crops, grass, or trees.

3. 2. All phases of water catching are included in this one term, vide Figure 5:—

(1) the ploughman's furrow, either covering the entire surface of the field or only run at spaced intervals.

(2) a double turn of a plough to throw up a ridge either 2 furrows back to back, or in multiple.

(3) shallow trench and ridge.

(4) deep trench and ridge, as first used in the Punjab in the Jaijon catchment in 1938.

(5) Bijapur bund built out of shallow borrow pits into a ridge with a more or less triangular cross-section.

(6) wattbandi with a contour bund built out of soil scraped from all over the field to form any shape of mound; this is the standard Punjab practice and is generally understood by all cultivators.

(7) the American broad-based terrace, with the cut and fill forming a much flattened hump and hollow. The only essential difference between the "Mangum" and the "Nichols" patterns is that the Mangum is more hump than hollow while the Nichols is more definitely an excavated ditch.

(8) basin-lister or scoop machine, making the entire field surface into a dense pattern of 10 ft. × 3 ft. basins.

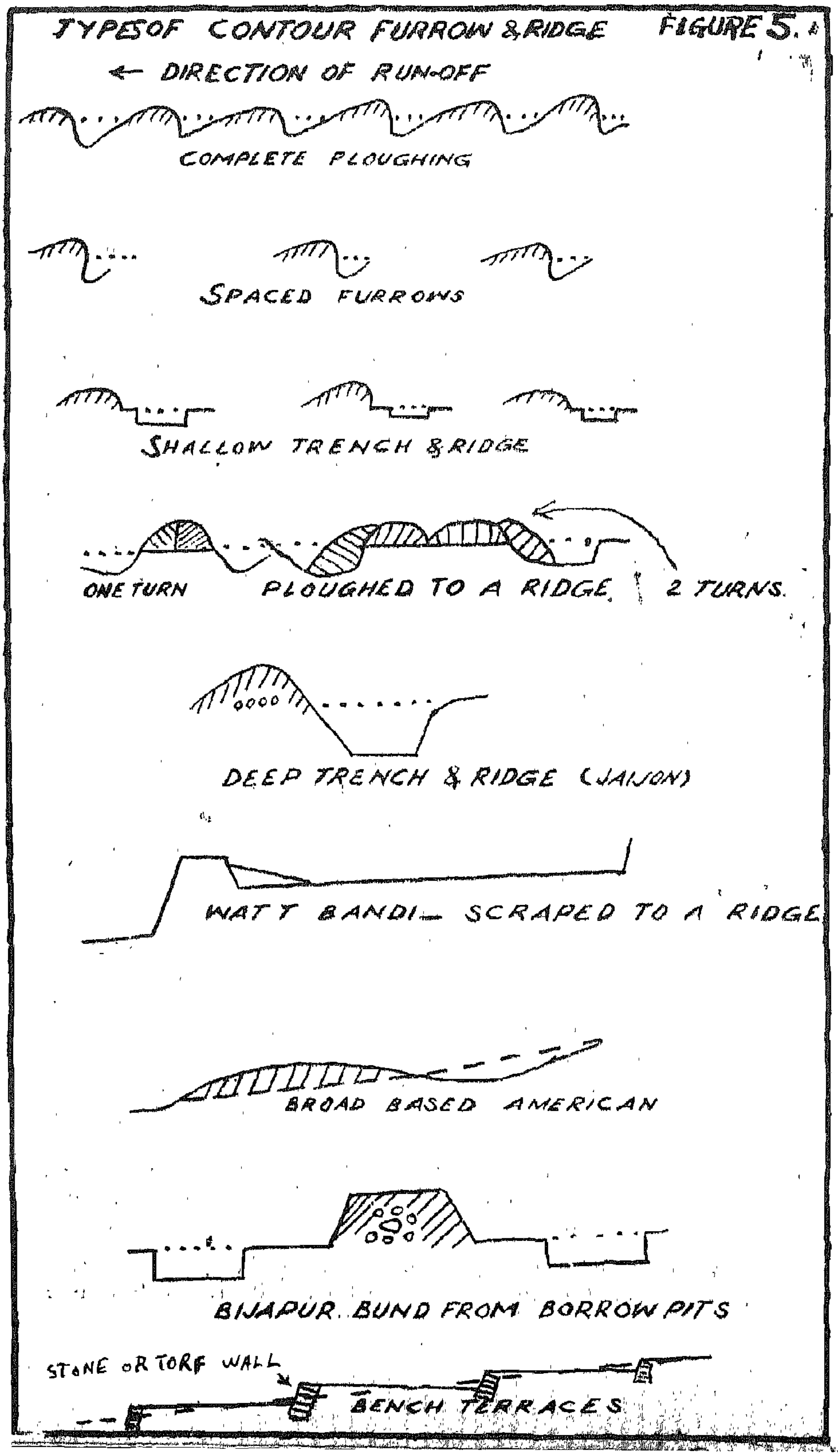

TYPES OF CONTOUR FURROW & RIDGE
FIGURE 5.
← DIRECTION OF RUN-OFF
COMPLETE PLOUGHING
SPACED FURROWS
SHALLOW TRENCH & RIDGE
ONE TURN
PLOUGHED TO A RIDGE
2 TURNS.
DEEP TRENCH & RIDGE (JAIJON)
WATT BANDI – SCRAPED TO A RIDGE
BROAD BASED AMERICAN
BIJAPUR BUND FROM BORROW PITS
STONE OR TORF WALL
BENCH TERRACES

PLATE 3 (i).

Watt bandi in Pail village in the Salt Range improved and strengthened as a result of a grant-in-aid provided under the Grow More Food fund in March 1946.—Para 3.5b.

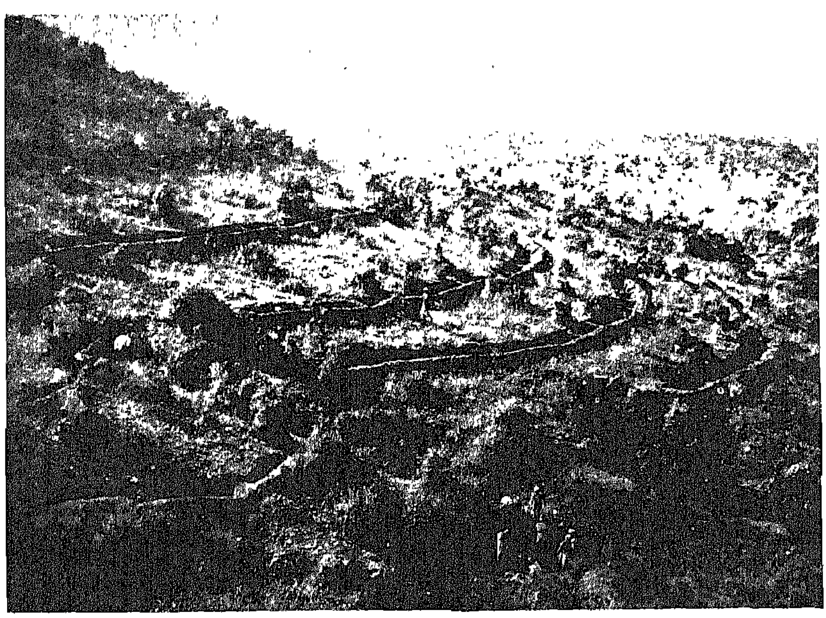


PLATE 3 (ii).

This shows that contour trenches are not straight lines, but must be laid out accurately level so as to catch maximum of water. Squad below is building a checkdam in the nala bottom.—Para 3.28.

Jaijon Hoshiarpur 1939.

(9) typical rice-field pattern of small plots completely levelled and each with a puddled clay bund round the downhill edge.

(10) bench terracing, commonly used on hillsides too steep to permit of a bund raised above the level of the field itself. Each bench is a flat step between the inside hill face and the outer terrace wall though the ideal is to have a slight reverse slope into the hill and thus secure a good catch of water.

3. 3. The success of any of these types depends upon accuracy of alignment true to the contour; improperly constructed ditches and furrows may add to the erosion rather than stop it, as is frequently the case when a series of short interrupted trenches (often but wrongly called "contour trenches") divert water on to the edges of gullies already cutting actively.

3. 4. The only justification for departing from the strict contour is when long lengths of terrace carry so much run-off that there would be a constant risk of breaching unless the water were drained off. This can be done by aligning the bund, or rather the channel behind the bund, on a slight slope as is done in the case of a diversion ditch, whose function is not to hold up still water but to lead it gently away; this is known as the ***graded channel type;*** details of which are given later in para 3. 24.

II. *Contouring in Plough Land.*

3. 5. *Three Topographical Classes.*—These notes are restricted to plough land only. The capacity of rain for destroying and removing unprotected soil is terrific; falling at 20 m.p.h. (as is frequent in storms) 2 inches of rain per acre produces 6 million foot-pounds of kinetic energy, much of which is expended in loosening, churning up, and removing in suspension the most valuable crumb structure of the top soil. In considering erosion losses fields may be grouped roughly into 3 classes according to their topography:—

(a) Comparatively flat *barani* cultivation. Most people think that erosion is not a serious matter on such land, but the run-off data for the Sholapur Experimental Farm in Bombay collected by Mr. N. V. Kanitkar, showed a loss of 133 tons of soil per acre per annum from a well tilled field on a gentle gradient of 1 in 80, indicating a very serious state of affairs where one would least expect it. (*Ind. Jour. Agric. Sci.*, 1941).

(b) Gentle slopes in the highly eroded foothills and in the rolling sandy uplands such as the Punjab Doaba.

Here the need for contour terraces and contour ridges (*wattbandi*) is fully appreciated by many cultivators but unfortunately is not practised consistently. It is most fully practised in the arid districts e.g. Mianwali, and the standard deteriorates as the rainfall improves and the need for saving every drop of rain becomes less urgent. The cumulative run-off from big blocks of such rolling land forms a serious problem unless every field is fully fitted with *watts*, and often spillways are also needed. Plate 3 (i).

(c) Steep slopes where permanent cultivation is possible only with elaborate terrace walls of stone or turf. Unterraced cultivation on steep slopes known variously as "shifting cultivation", *nautor*, *rab*, etc., is inevitably so destructive that after a few years the field reverts to stony scree.

3. 6. The protection of ploughland from erosion can be reduced to (a) the protection of the surface against falling rain (b) the infiltration of water into and through the soil (c) leading off the excess in such a way as to deprive it of power to do damage.

In practice there are four lines of defence, viz. :—

(a) maintaining a plant cover in terms of crops; leaving stubble after crop is cut; green manuring; or the sowing up of bare fallow with a protective cover, preferably leguminous, but grass has great possibilities.

(b) maintaining the soil in a porous condition by means of manuring, mulching, and other tillage practices such as subsoiling.

(c) the interception of water by means of ploughing along the contour; the proper levelling of each field; contour ridging or wattbandi by which each field is turned into a saucer; basin lister ploughing which digs a complete series of small saucers.

(d) the proper construction of escapes at every stage from top to bottom of each block of fields and the disposal of accumulated run-off so as to render it harmless.

While these principles appear simple, departures from standard practices to meet local peculiarities require much careful investigation and practical trial before being applied. If the farmers' confidence is shaken by finding our advice on any point is wrong, it may take years to recover this confidence.

3. 7. *Cures based on American experience.*

(a) *Terracing.*—The American broad-based contour ridge is out of the question for Indian bullock power and our usually shallow soils and in any case takes up too much room unless cultivated throughout. We have to substitute either *wattbandi* (narrow based ridges), or reversed-slope bench terraces, in both of which the whole of each field virtually forms a saucer.

(b) *Strip cropping* to break up big blocks of land under one highly erosive crop. This is not feasible for the ordinary small Indian field but might be practised by whole fields wherever a good alternative such as berseem or lucern is an accepted local crop, or where a leguminous cover crop can be introduced on bare fallow.

(c) *Abandonment of highly erosive crops* cannot be usefully recommended until we have found some equally marketable substitute for the given soil and climate. Speaking generally the *method of field cultivation* is in India a far bigger factor in causing erosion than the *choice of crop.* In this connection the new American practice of carefully preserving stubble and crop residues of all sorts on the ground and preparing the soil for the next crop by cultivating along the contour and disturbing these old crop residues as little as possible is recommended for wide trial under Punjab conditions and particularly wherever dry farming is considered essential.

(d) Local demonstration on a *project basis* for selected catchments has in America been replaced by a *district organisation* aiming at forcing every farmer in a whole district to adopt the recommended practices of field cultivation and land use. These district organizations correspond roughly to our soil conservation division for each civil district in which the soil conservation circle is functioning, but with this difference that in the United States of America much of the driving force comes from an elected body of farmers who are given very large powers to coerce the unwilling minority into doing what they are told to do, funds being collected by levy or cess to supplement the funds collected by government out of tax remissions.

3. 8. *Cures based on Indian experience:*—

(a) One great contribution which India has made to the problem is the fact that individual fields have been kept fully producive for centuries by means of skilful terracing i.e., bench terracing in the case of rice lands and *wattbandi* for other crops. Where *wattbandi* is not already consistently practised, it can be fostered quickly and on a wide front by contributing grants or with an adequate remission of revenue to reward each man who

puts his fields in good order. The need for coercion has already been accepted by the Punjab Government as necessary for important catchments, such as the Uhl hydroelectric supply, but has not been applied generally to ordinary *barani* land though it is visualised in the proposed application of section 5 A of the Chos Act to individual revenue estates. Remission of revenue as a means of encouraging *wattbandi* has never been made operative, but grants in aid are being given on a contributory basis in our soil conservation division.

(b) much slower but acceptable progress can be made (through *consolidation* of scattered holdings,) particularly if the method and layout of the new field pattern pays sufficient attention to slopes, run-off, and natural drainage problems as affecting roads, fields and water tanks.

(c) (*partition of undivided shamlat*) (common holding) is highly successful wherever there is a genuine land hunger. Fresh allocations of waste are rapidly made cultivable by energetic individuals, and the uncultivable remainder is closed to form private hay fields and small blocks of forest. In Jhelum district however, the area actually improved by this method is usually only 10-15% of the total divided *shamlat*.

(d) better farming societies, and land reclamation societies and punchayats, all of which should have *wattbandi* as part of their creed and in their byelaws.

(e) direct action by agriculture and forest departments by means of demonstrations, prizes to good workers, lectures and "weeks" may spur an intelligent minority but has little effect upon the lazy majority of cultivators, so that some threat of coercion must be provided by statute, and is now available through the application of section 5A which was added to the Punjab Land Preservation (Chos) Act in a 1944 amendment.

III. *Recommendations for Contouring in Plough Land.*

3. 9. The Punjabi cultivator prefers square fields. Except in the single case of hill rice cultivation which minutely adheres to the contour he has attempted to enforce a grid of square fields on to a country of round contours. The result has been (a) that the lowest corner of each field is the wettest and most easily breached, and (b) that a great deal of unnecessary earth moving goes to make watts which depart from the contour. In the case of the rice fields on steep slopes he has realised that the cost of square fields would be prohibitive and he has therefore followed the contour; most individual rice fields are kidney-shaped because they follow the contours of the hillside. This is the principle which we wish to have adopted for all *barani* land, whether under agriculture crops, grassland or trees.

3. 10. In the Punjab we have delayed proper *contouring* in the hope that at the time of consolidation of holdings the land will be contoured. In Bombay Presidency they have done better by carrying out the contouring first; the old field boundaries remain in use until consolidation is introduced, but at consolidation the *contour ridges* automatically become the new field boundaries. for by then the cultivators have come to appreciate their value. Contour cultivation must disregard old field boundaries and straight lines completely, following curved lines wherever this has to be done in order to stay on the level.

3. 11. Contouring of fields is best understood in the arid zone where it is essential to ensure the trapping of the entire rainfall, but it is equally necessary in the wet zone in order to prevent erosion on land that unprotected would suffer from gullying or sheet wash. It is equally important in flat land liable to suffer from wind erosion; for this latter, ridges are more effective than trenches, but on clay, furrows or trenches are better than ridges.

3. 12. The idea is commonly held by many civil officials that one *"wattbandi week"* each year in a district is effective. It may salve the civilian conscience, but the fact remains that proper field technique is not gained through a burst of feverish activity once a year, but is based upon a *habit of mind.* Run-off control only starts with the making of a *watt;* the rest of the cultivator's life must be a study of how this start in run-off control can be improved upon. Maintenance must be preached until it is done as a matter of course. We are far removed from this standard.

3. 13. Another common misconception is that a *watt* to be effective must be an enormous engineering feat. This is entirely erroneous. On level land or gentle slopes on sandy loam the most efficient watt for wheat is a ridge about 1 ft. to 18 inches high and 2 to 2½ ft. wide at the base, running along the contour and repeated at intervals of say 12 to 15 yards. If these are accurately contoured they can take care of the whole of the rain of even very severe storms provided that drainage does not accumulate and pass from higher fields to the lower ones of a block. Such frequent *watts* are however generally disliked by the cultivator as they interfere too much with his ploughing so bigger but less frequent bunds are therefore preferred.

3. 14. The vertical drop between 2 consecutive watts is determined by the gradient and the minimum width demanded for ploughing. On land of less than 6% slope, 100 ft. width makes a reasonable field, but anything steeper than this quickly runs into difficulties, for watts on narrow fields take up too much of the ploughable surface, until for 8% slope and upwards a bench

terrace without a *watt* is preferable. A schedule is given below of recommended spacing and heights of *watts* based on American data but altered on the basis of contouring demonstrations actually carried out in various Punjab soil conservation divisions.

3\. 15. *Table of recommended vertical falls between terraces in relation to land slope.*

Slope. in feet. per 100 ft.	In degrees.	Equivalent gradient (approx).	Vertical fall from terrace to terrace.	Horizontal distance from bund to bund. average.	maximum.	Type of work.
1 ft.	0° 34′	1/100	2 ft. 0 inches.	180 ft.	230 ft.	
2	1° 09′	1/50	2 „ 6 „	120 „	150 „	
3	1° 43′	1/33	3 „ 0 „	100 „	140 „	wattbandi
4	2° 17′	1/25	4 „ 0 „	100 „	110 „	& contour
5	2° 52′	1/20	5 „ 0 „	100 „	120 „	ridging.
6	3° 26′	1/17	6 „ 0 „	100 „	110 „	
7	4° 00′	1/14	5 „ 0 „	60 „	80 „	
8	4° 34′	1/12	4 „ 3 „	50 „	55 „	
9	5° 09′	1/11	4 „ 6 „	45 „	55 „	
10	5° 43′	1/10	4 „ 9 „	45 „	50 „	Bench ter-
11	6° 17′	1/9	5 „ 0 „	45 „	50 „	racing &
12	6° 51′	1/8½	5 „ 3 „	40 „	45 „	complete
13	7° 24′	1/7½	8 „ 0 „	60 „	70 „	levelling.
14	7° 58′	1/7	5 „ 0 „	35 „	40 „	
15	8° 32′	1/6½	6 „ 3 „	35 „	40 „	
20	11° 19′	1/5	8 „ 0 „	35 „	40 „	

3\. 16. Nothing of over 20% (1 in 5) should be terraced, except by mattocking contours for grass or tree sowings, or by short lengths of interrupted but carefully contoured trenches for afforestation. This table shows that on slopes with a greater fall it will be necessary to build higher mounds and to reduce the distance between terraces according to the grade. Narrower and deeper ditches should be cut to occupy as little land as possible for such ditches and mounds cannot be cultivated. The upper limit of slope for which a ditch and mound is practicable for field cultivation is reached much earlier than where a very narrow ledge is being provided for afforestation or *bhabbar* grass planting.

Where the soil is a clay or heavy loam which is likely to hold the water too long on the surface and damage the crop, big *watts* should not be made but instead a series of smaller *watts* 6 inches high and 1½ ft. at the base should be put in at closer intervals of about 15-20 ft. apart; (ploughing ought to be done along the contour and can therefore run between these *watts*). This is more or less the technique of the hill rice field applied to other crops. For certain crops such as cotton, deep accumulations of rain water are likely to be harmful, particularly to a young crop.

3\. 17. *Bench Terraces for Steeper Slopes.*—Where the slope is steeper than 8% or 1 in 12, *wattbandi* becomes expensive and is

less effective than benches separated by upright terrace walls of turf or stones. The ploughable surface should be sloped back into the hill with a reverse slope so as to hold up water in the part cut deepest into the hill. Terrace walls can be greatly strengthened with suitable hedge plants such as *Agave* and *Opuntia* and can be made to produce income by planting with fruit trees, bhabbar grass, bamboos and hedgerow timber.

Wherever there are old-established settlements on hilly land, some form of bench terrace has been evolved, and in fact it is safe to say that where a satisfactory terrace has not been found, that community has had to move on, for the loss of soil has inevitably been so great that farming became impossible there. The best example of complete bench terracing is seen in the hill rice cultivation, where the ruling factor is the retention of water for long periods in each field. Unfortunately for other crops the same meticulous care is not taken and the fields between the benches are themselves sloping, so that serious soil loss continues, in spite of much hard work and expense having gone into the construction of the stone walls which form the benches.

Where a fairly broad field is wanted, stone terrace walls are essential, but where a narrower field will serve, the terrace walls can be of built-up turf or of a grassy bank, but the safety of these is constantly threatened through the common practice of allowing grazing on bare fallow, when the hungry animals tear these grassy banks down and leave them weakened. They also get out of shape through ploughing every year right up to the edge, thus eventually making the turf wall bulge outwards. In this condition a heavy fall of wet snow may easily start a snow avalanche from the collapse of one of these bulgy parts. Once an avalanche has started it gains momentum and is apt to carry away the stronger benches lower in its path.

One advantage of a properly vegetated bank over a stone wall is that if properly maintained it is much more absorbent. With good turf banks maintained without bulges and with the ploughed land properly levelled between them, such land is not likely to develop gullies, because there is so little run-off. In the case of stone walls the absorption is less. In either case the natural drainage channels on the hillside should be left out of the benched area, unless the entire area of a small catchment is completely benched from the top downwards.

Another advantage of a turf bench wall as compared with a stone wall is that the snowfall is itself better disposed of, and frost does less harm. Freezing of waterlogged stone terraces often leads to the terrace wall collapsing. Under hard winter condi-

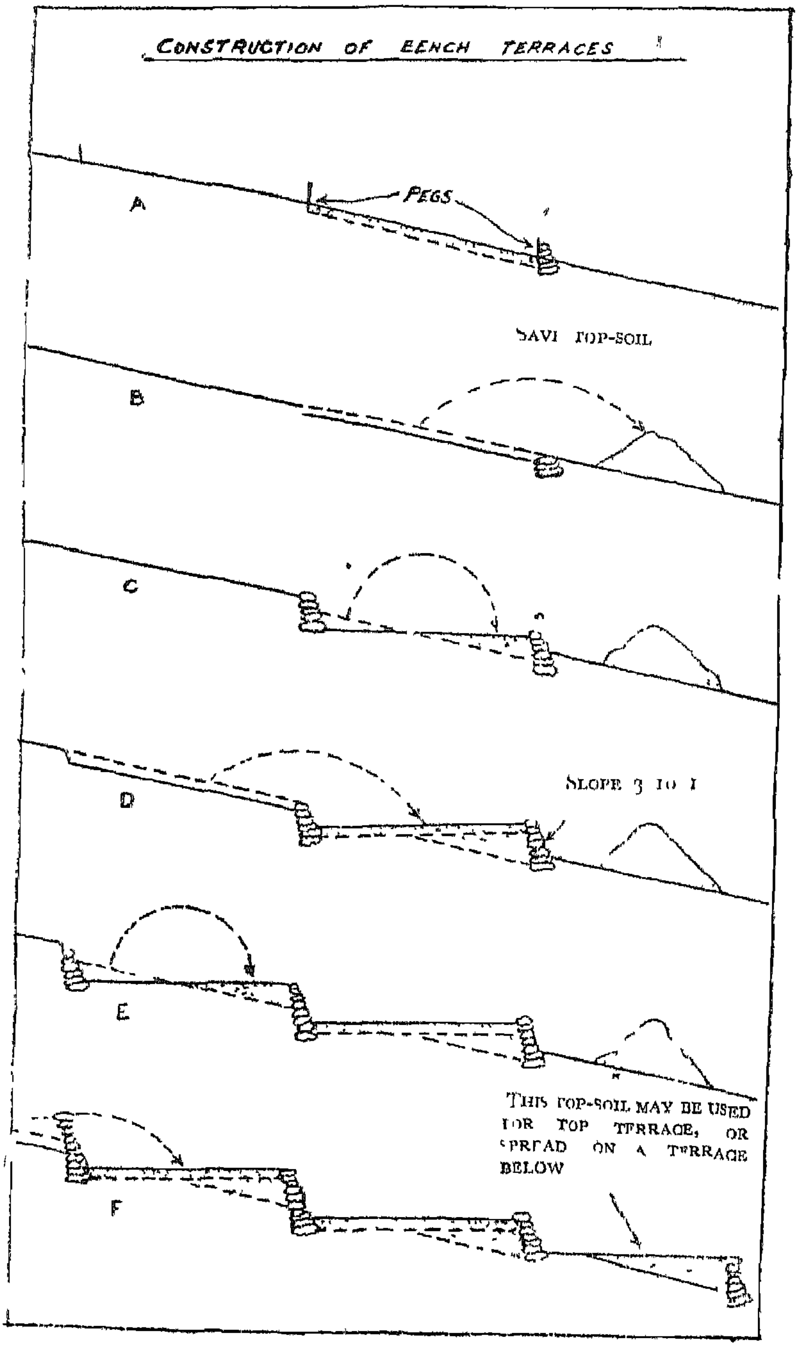

CONSTRUCTION OF BENCH TERRACES
A
PEGS
SAVE TOP-SOIL
B
C
SLOPE 3 TO 1
D
E
THIS TOP-SOIL MAY BE USED FOR TOP TERRACE, OR SPREAD ON A TERRACE BELOW
F

FIGURE 6

tions snowfall is common down to 4000 or even 3000 feet in the Punjab, but it never lies long at these levels. Snow falling upon hard frozen bare earth will disappear immediately the thaw comes, whereas the snow which has fallen on grassy benches will be all absorbed on the fields where it has fallen. Generally speaking, and apart from the rice-cultivation blocks of fields, the bench terracing in the Punjab hills is too wide apart, and efforts must be made to reduce the width of fields by inserting intermediate walls in the blocks of fields already made.

The need for preventing bare fallow and for keeping these bench terraced fields under some sort of vegetation has been emphasized in paras. 5. 22. and 5. 30. The need for restricting *nautor* (application for permission to break fresh ground in the hills for making fields) has been emphasized often in the past (See Sir H. M. Glover's Erosion in the Punjab; its Causes and Cure, page 33), but too often permission is still obtainable and a fresh block of fields becomes established where previously forest or grass-land was before. Strict vigilance is therefore required from all forest officers serving in the hills, and their aim must be not to prevent such *nautor* entirely, but to see that both old and

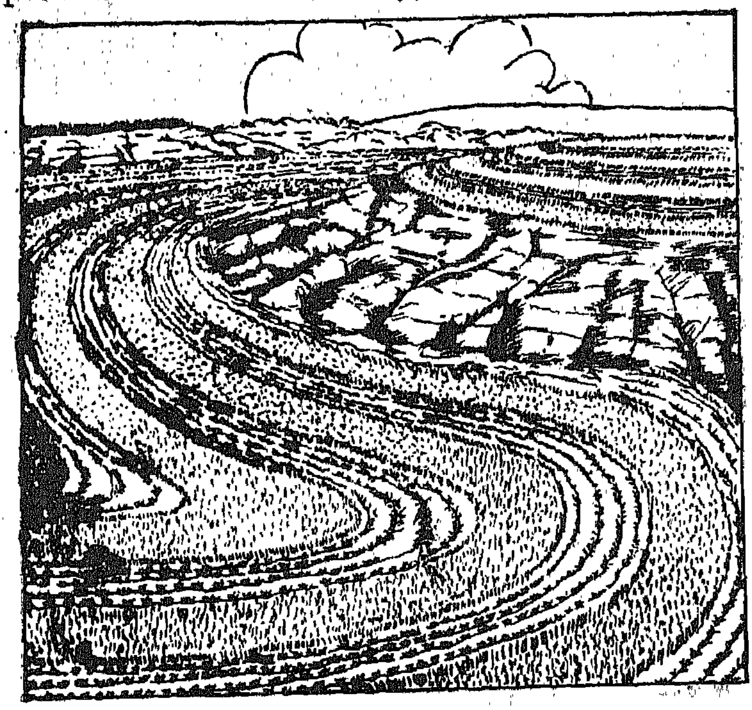


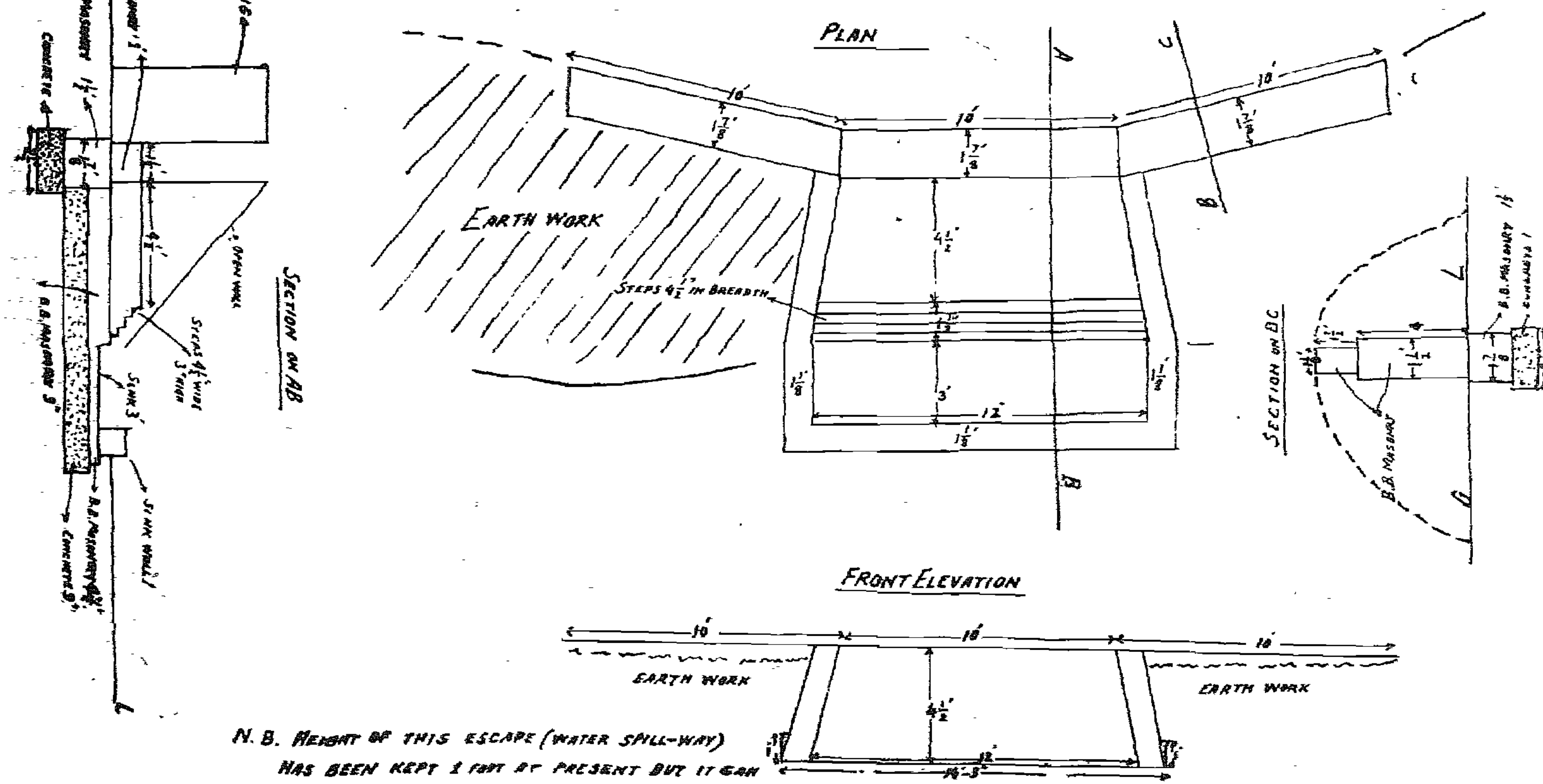
FIGURE 6A

Critical slopes, where erosion progresses more rapidly than on lesser slopes, should be taken out of cultivation and seeded to perennial forage crops before erosion destroys the sole above the critical point or damages by sedimentary deposits the productive land below. Para. 3.18.

Figure 7. ref. para 3-19.

STANDARD PLAN OF A MASONRY ESCAPE WEIR FOR FIELD OUTLET

(Based on the Experience of those made in SHAKARGARH)



N. B. Height of this escape (water spill-way) has been kept 1 foot at present but it can be raised gradually.

new cultivation is fully bench terraced, and that the walls of either grass or stone are maintained at a safe pitch of slope, say 3 or 3½ in 1. A good rule to introduce is that no *nautor* application will be sanctioned for anyone whose old fields are not already fully and efficiently terraced.

3. 18. Fields of a slope steeper than 15% or 1 in 6, should be withdrawn from ploughing as they are not usually worth the heavy labour of making benches very close together. The whole area should be planted with a permanent crop such as bhabbar grass, fodder grass, bamboos or trees. All of these can be established more easily if the ground is dug with shallow trenches running along the contour, or failing this a carefully contoured ploughing with a heavy metal plough or digging in lines with a mattock or *pharwa*. Plate 3 (ii).

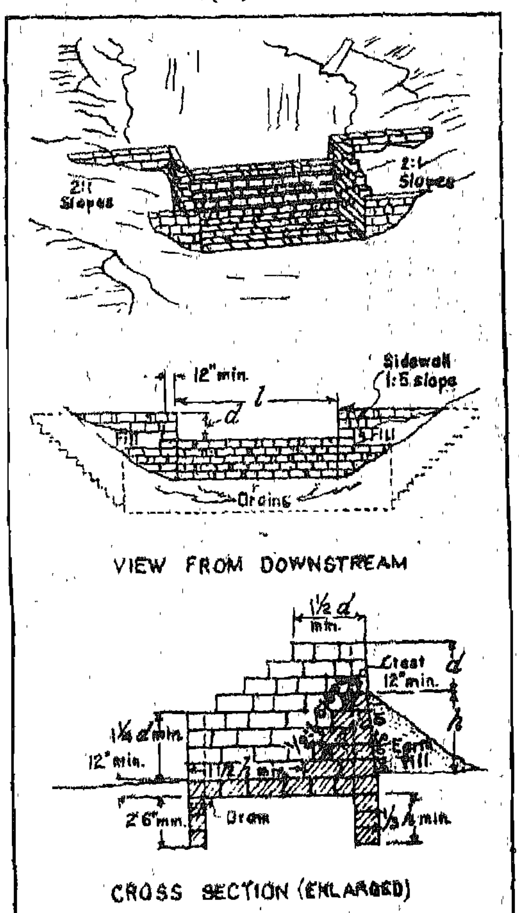


FIGURE 7A
Design for small rubble masonry dam where the height h does not exceed 5 to 6 feet (Soil Conservation Service, U. S. A.) Para. 3:19

3. 19. On sandy absorptive land escape outlets should be grassed down with dub grass dibbled in (see para. 3. 45). On clay or non-porous soils where fields occur in big contiguous blocks some form of masonry sill is required for the escape channel. One spillway commonly used in the Punjab foothills is of brick and cement with a sloping front and costs about Rs. 25. The provision of a stilling pool at the bottom of the spillway is essential to stop undercutting of the structure by the seepage of water around the base of the wall. Figures 7, 7A, and para. 3. 46, also 6. 10 onwards.

3. 20. The maintenance of *watts* in wheat land is seriously threatened by bare summer fallow remaining untouched until towards the end of the monsoon when ploughing begins again. The amount of sheet erosion caused by the early monsoon storms is immensely serious and could to a great extent be prevented by getting the ground ploughed and *watts* repaired before the monsoon breaks and again at frequent intervals through the rains.

3. 21. When introducing run-off control measures for the first time in badly eroded land it should be realised that with the top soil already gone, the subsoil, often an intractable clay, is incapable of absorbing much water. Here spillways should be the basic patern of the plan and the accompanying *watts* merely a means of leading the water towards each spillway. This will be particularly necessary when mechanical equipment is used to break down steep slopes, as an entirely new drainage regime will have to be worked out.

3. 22. The entry of outside drainage onto blocks of fields from uphill should be prevented by *diversion drains* wherever this accumulation of water is likely to cause damage. On the other hand in areas of low rainfall, run-off from uphill can profitably be led onto the field to be absorbed there instead of being wasted.

3. 23. For *watts* in sandy and porous soils no side slope should be allowed and the top of each *watt* should be dead level from end to end, but should be built broader and stronger at points where *nakkas* or spillways are inserted and also where any natural dip in the ground behind is likely to collect much water.

3. 24. Long lengths of terrace can be planned in one of the following 3 categories:—

(a) the absorption type, dead on the contour throughout except for upturned closed ends.

(b) for rainfall of over 30″ such a terrace would be certain to breach so the ends are left open, or spill-ways provided.

AERIAL VIEW OF A CONTOUR-TERRACED FARM. THE TWO TOP TERRACES ROUND A KNOLL BEING DEAD LEVEL AND WITHOUT ANY OUTLET. OUTLETS OF LOWER ONES ARE LED TO WOODLAND BY A DRAIN.

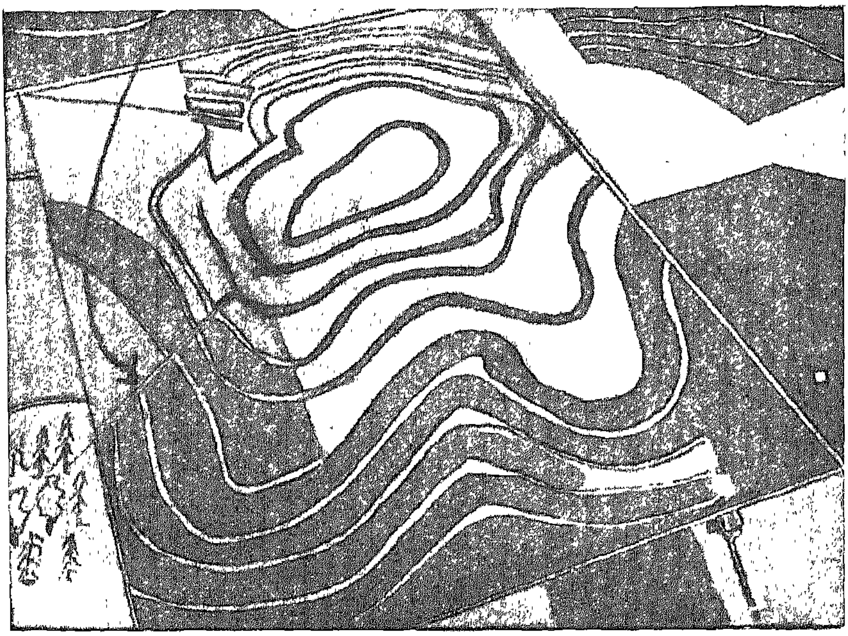


FIGURE 8.

(c) the graded terrace with a middle section dead on the contour and the end sections with an intentional fall to lead the water away gently to prepared spillways.

For clays and other less porous soils a slight side slope should be given so that the bottom of the *watt* channel has a slight fall toward either or both flanks not exceeding 6 inches per 100 feet of its length. This will ensure that stagnant water does not remain indefinitely on surfaces which will not absorb any more. The following is recommended as an adaptation of American practice for establishing side-wise drainage in very long lengths of wattbandi:—

Table of grading of side-wise (graded channel) drainage in relation to land slope and length of terrace.

Length of terrace in ft.	Land slope 5%	10%	15%
	on clay soil,	inches drop per 100 feet length.	
0 to 400	0	0	0
400 to 700	2	2¼	2¾
700 to 1000	3	3½	4½
1000 to 1300	4	4¾	5½
1300 to 1600	5	6	7
	on sandy soil.		
0 to 700	0	0	0
700 to 1000	1¼	1¾	2½
1000 to 1300	1½	2½	3½
1300 to 1600	2	3	4

The middle of the compartment will thus have dead level terraces but in a very wide compartment they will have a slight cant to either or both ends to ensure against breaching.

3. 25. *Maintenance.*—An analysis of old contour terrace areas in a variety of American soils shows clearly that terracing alone is not sufficient to stop field erosion. Other points which need attention in both planning and maintenance are:—(1) single units of field between terraces too broad—i.e., terraces wide apart for the given slope, (2) wrong location or absence of outlets and sills, (3) terraces too long, (4) higher catchment draining into terraced area, (5) too steep a sidewise alignment of terraces may allow erosion along their length (over 6" drop in 100 ft.). ("A study of Old Farmer-Built Terraces" by Carnes & Weld; *Jour. Amer. Agri. Engineering*, October 1941). To these may be added the common Punjab experience of neg-

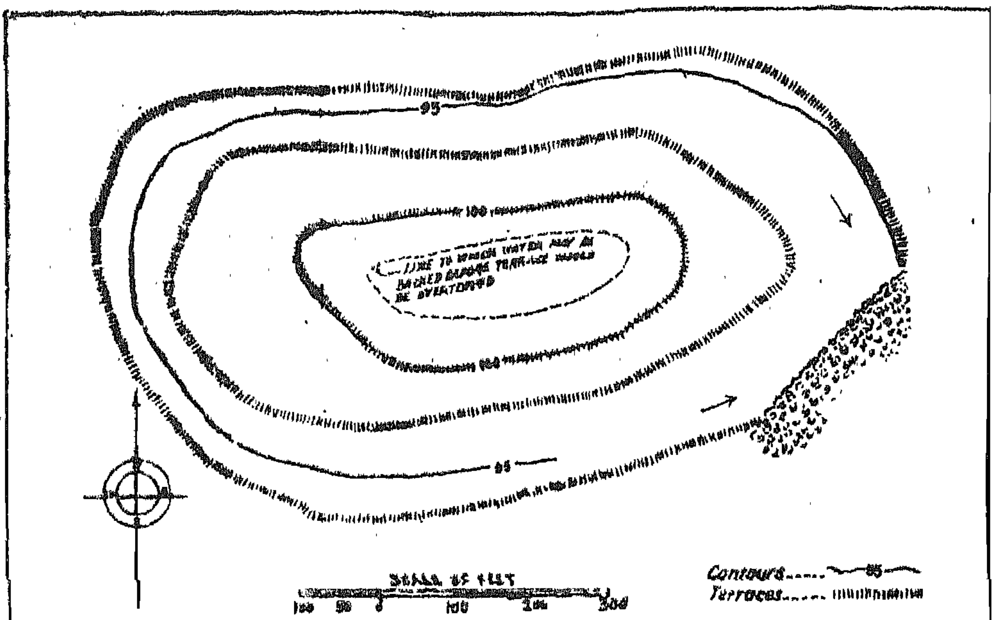


FIGURE 8.—AN EXAMPLE OF LEVEL TERRACES ENCIRCLING THE TOP OF A KNOLL. THE UPPER TWO TERRACES HAVE NO OUTLET.

lected maintenance. In many Punjab districts *watts* were built by returning soldiers nearly 30 years ago but have since been neglected and remain as isolated humps in eroding fields. Similarly one finds brick spillways standing as isolated and useless tombstones in the alignment of a *watt* or *bund* which has not been maintained at the correct height, and a cattle-track or foot-path has eventually dug so deep as to let all the water through there instead of over the sill.

When the farmer has realised the great benefits derivable from terracing he may himself take care of the work, but from the outset he ought to be taught how to maintain the ditches and windrows in good condition. All breaches that occur must be repaired after each storm and not left till the end of the monsoon. *Dub* grass or any good local shrub should be planted on the bunds, which should be raised at each ploughing, when the drains should also be cleaned. He should also attend to the repair of outlets.

3. 26. *Increase of Yields of Crops.*—The following figures collected by their Land Improvement Section for six centres in Bijapur (Bombay) for the rabi harvest of 1943-44 give an idea

of the comparative yields in bunded and non-bunded areas with and without Dry Farming operations.

	Average yield. lbs. Grain	p.a. Fodder	Maximum yield. lbs. Grain	p.a. Fodder	Minimum yield. lbs. Grain	p.a. Fodder
No bunding, no Dry Farming	274	507 (163 acres)	401	675	145	400
Bunding, but no Dry Farming	344	643 (234 acres)	625	1246	158	310
Bunding, and Dry Farming	646	1057 (295 acres).	916	1530	386	747

Somewhat comparable increases in cereals and fodder grass crops have been reported from all of the Punjab soil conservation divisions as a result of bench terracing or wattbandi as compared with the previous yields from the same land before levelling. But with thin soil and an infertile subsoil, the crop output may be lowered for some years by wattbandi in the same way as often happens after deep ploughing; this is due to the exposure of raw mineral subsoil.

IV. *Contouring for Afforestation and Grass-land Improvement.*

3. 27. In the case of grassland and pastures with appreciable slopes, American experience has shown that big bunds wide apart are less efficient than a greater number of small ridges placed closer together—i.e., at shorter intervals down the contour, so that the pattern is reduced to that of ordinary plough furrows cut with a "*raja*" or a mould-board or other heavy plough, cutting say 6" furrows spaced 30 to 50 inches apart according to the porosity of the soil. A 3-inch rainfall can be held by furrows with half a square foot of cross-section, 2 ft. apart centre to centre. Porous soils need fewer furrows than this When such land is eventually reopened to grazing these furrows will be less easily damaged by the animals than deep ditches and high ridges would be. On the whole a furrow is better than a ridge because it revegetates more quickly and usually produces better quantities and quality of fodder grass. The furrow must however be reasonably large; *the ordinary country plough is useless.*

3. 28. In the case of the deep trenches which were dug at Nurpur in Kangra in 1937 for demonstrating the progress of natural grass recruitment, the ground was a very infertile subsoil clay exposed by years of sheet erosion, and the natural grass improvement has been very slow indeed, partly because the area has never been fully protected, and partly because no planting of any sort was done. The expense of trenching in such areas is not justified unless it is going to be followed up energetically

with planting and sowing of desirable species. On slightly more fertile loam and with complete protection, as we have had in the Polian-Jaijon trenched area of Hoshiarpur, natural grass recruitment has been good and the 18 inch deep trenches dug in 1938, although very little silted, are now invisible from the opposite hill side because the plant cover is so dense. (Plate 4).

3. 29. In the case of arid zone grass crops on level ground, the Hissar Livestock Farm has shown that a good and apparently permanent grass cover can be established on land that was previously completely wind-swept as it lay in the path of regular dust-devils, by means of ploughing with a heavy plough and doing a double turn every 15-20 ft. to build up a very small ridge into a criss-cross pattern known locally as *kiara-bandi*. The grass used is *anjan* (*Cenchrus ciliaris* Linn., formerly and more commonly *Pennisetum cenchroides* Rich.). In Hissar practice this grass crop is cut for hay in years when the growth justifies it (possibly 3 out of every 5) and in the drier years it is grazed but the grazing is strictly regulated by keeping a fairly large number of animals on each field for a short time only and moving them off as soon as the grass has been eaten down to a 4" stump. (Plate 5 i).

3. 30. Most of our work with *bhabbar* grass (*Eulaliopsis binata*) which is earning very large sums of cash for the foot-hill villagers, has shown that although it takes many years for ordinary transplanted clumps on a sloping hillside to become sufficiently well established to give a worthwhile commercial yield, the same size of transplant in the immediate neighbourhood of a trench gets into its stride very much quicker. Trenches on poor sandy soil under a thin canopy of chir pine in Sidh Chalet, Hoshiarpur division, gave a yield per acre of 0, 5, 40 and 60 maunds in the first 4 years after planting on trenches, as compared with hardly any appreciable increase beyond the 10 maunds per acre of the second and subsequent years from untrenched hillside planting.

3. 31. In the case of the Silviculturist's four replications of arid zone afforestation plots for areas with a rainfall of 6", 9", 14" and 20", a similar type of *kiarabandi* to the Hissar grass sowing technique was used and the results obtained have been most encouraging with a survival into the third year of something between 2000 and 4000 plants per acre with all the species tried, namely *Acacia arabica* and *farnesiana, Prosopis glandulosa* and *juliflora,* and *Salvadora oleoides.* This was achieved with considerable attention to soil working and mulching which is an absolutely essential part of the technique.

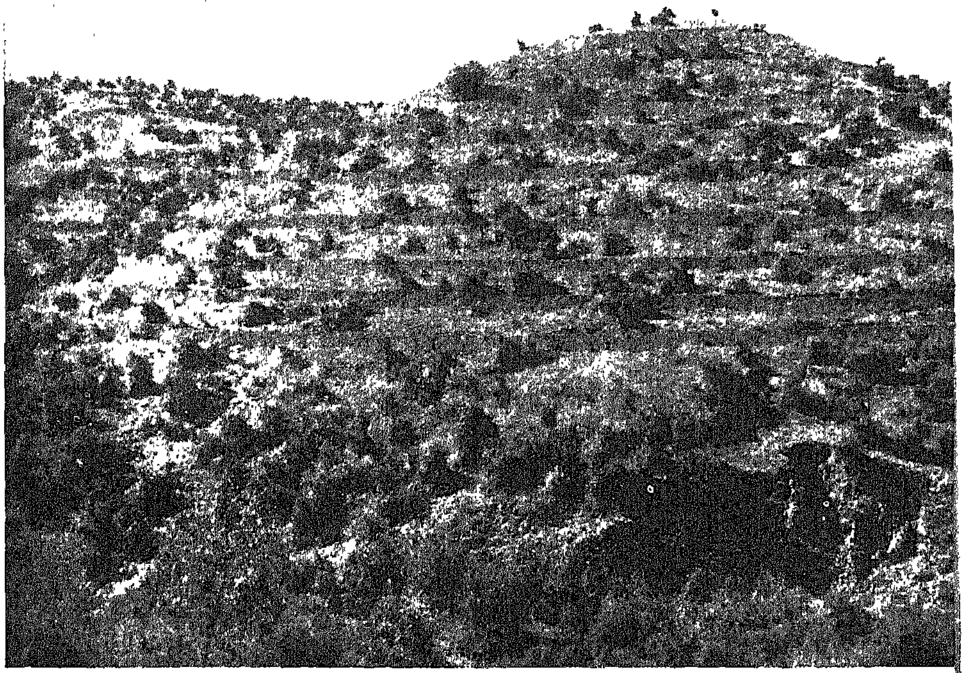


PLATE 4. (i)

Jaijon trenches newly dug in 1939.—Para 3.28.

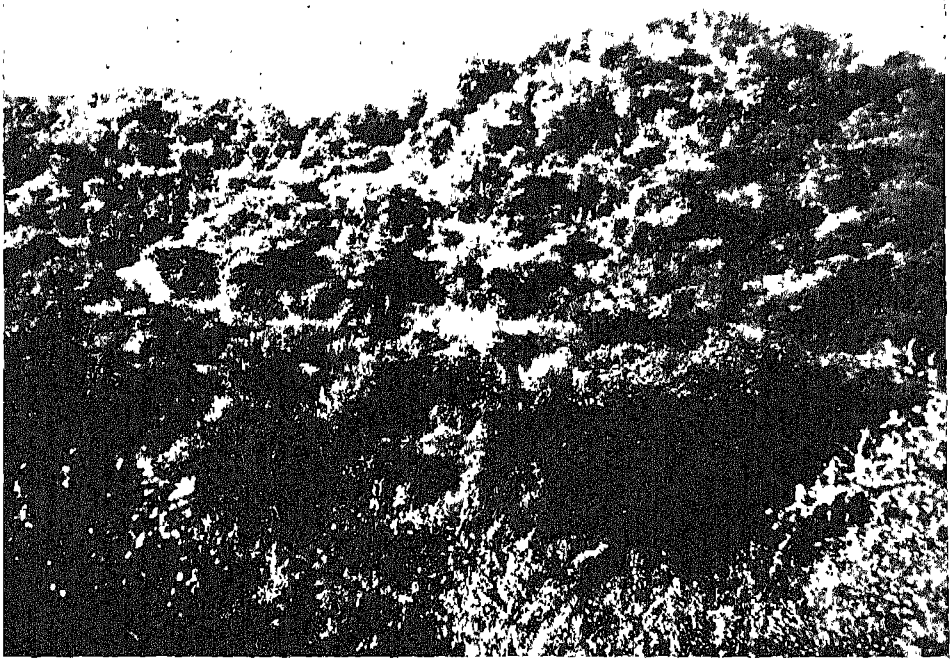


PLATE 4. (ii)

Identical view of the Jaijon trenched area in 1945 showing remarkable recovery of grass & tree growth. The trenches have not been silted up and are still functioning

3. 32. Further evidence of the value of water catching for afforestation crops is to be seen in the Pabbi hills of Gujrat where work has been in progress off and on since 1866. Where sowings have been done on the open slopes without any form of water impounding, *Prosopis* trees which must now be of any age upto 40 or even 70 years old have put on very little increment and the wood is so dense that the individual rings are hardly distinguishable, whereas the same species and even more exacting ones such as *Dalbergia sissoo, Albizzia lebbek,* and *Gmelina arborea* have produced trees of 10" diameter in 20 years in the neighbourhood of the earth bunds behind which the greater part of the local rainfall is stored beyond the monsoon season. The importance of all this is clear. If we are ever to grow either shelter-belts or timber trees in the arid zone we must concentrate upon the details of a successful technique of catching all the rain.

3. 33. In the choice as between short lengths of interrupted trench and continuous and fully contoured berms there can be no doubt about the higher efficiency of the latter type, and a continuous line accurately contoured should always be aimed at except where the ground is so steep and stony as to render this impracticable.

V. *Cost of Terracing and Trenching by Hand.*

3. 34. The cost of all forms of contour ridging will be higher in sticky clay than in loamy soils so that the reclamation of badly eroded uplands will inevitably cost more than the improvement of areas which have remained in cultivation and have been looked after by the cultivators. The financial return is also likely to be less from neglected land as it will inevitably take many years to rebuild the former fertility and the actual operation of building any sort of terrace will tend to throw up less fertile subsoils to the top. The actual cost of digging or ploughing can be roughly estimated on the basis of the work entailed, but will not cover subsequent operations of sowing, resowing, weeding, mulching, repairing breaches etc., and it is in these latter that the extra cost on clay soils becomes apparent rather than in the initial operation.

3. 35. Ploughing any average acre of sloping land with a "raja" plough may be taken at Rs. 12. Digging 10×1×1 trenches at 15 ft. horizontal interval and with a berm continuous along each contour row costs Rs. 16 on the basis of 14 annas per trench. The prewar provision of Rs. 8 per acre for 10 ft. trenches allowed only 100 trenches per acre, and these were scattered irregular-

ly and not linked up in continuous contour lines. Any combination of spaced furrows cut either by plough or by hand should cost less than this. A deep trench and ridge of the Jaijon type, and a Bijapur bund with shallow borrow pits will both cost about the same per running foot, so the cost per acre varies considerably with the horizontal spacing required. As practised in the dry areas of Bombay Presidency this consists of a complete network of low bunds laid out strictly along the contour, of average size 8 ft. base × 3½ ft. height × 2 ft. top width but shape and size varying in different soils. The horizontal spacing (mostly on very shallow slopes) is 70 ft. apart. The cost averages Rs. 12 per acre with famine hand labour but this includes the cost of survey and alignment and some overhead for superior staff. The owners are asked to repay 75% of the cost in easy instalments, and there is legal provision to enforce proper maintenance of the bunds once made, (a very essential point). On gentle slopes unobstructed by tree growth the shallow borrow-pits are cheaper, but on steeper slopes carrying scrub forest the Jaijon trench and ridge is cheaper and more efficient as a water conservation measure.

3. 36. Bitter experience in the Uhl valley has taught our Punjab department that *the trenching of very steep slopes is quite impracticable*. (R. M. Gorrie: *Indian Forester*, June, 1946). The steeper the hillside the more the work will cost for anything more than a single plough furrow, owing to the difficulty in providing a stable outer edge to the berm of the trench. It is important to remember that there is an economic upper limit of slope for any elaborate form of terracing, and we should keep strictly to the well established American convention that any land of over 20% slope (1 in 5) *should not be trenched or terraced*. Reclamation of all land steeper than this must depend upon less ambitious types of soil working and it would be wise to keep to mattocking contour lines with a *pharwa* or mattock until we have acquired more experience in the use of machinery.

Experts differ as to the steepest hillside on which a D 2 or Ford Ferguson tractor of the small compact type can profitably be used for afforestation on cut ledges; the British convention is 1 in 2½, but Assam and Burma war-time road-building experience points to this being exceeded, and thus opens up great possibilities for the reclamation of hitherto unproductive hill jungle land, particularly in areas of low rainfall, with a small and compact tractor pulling a basin lister with a single scoop.

3. 37. The cost of wattbandi and contour ridging to render land fit for cultivation is very much heavier than any of the above types of work and in actual practice using bullock drawn *karahs* varies from Rs. 40 per acre to 550 per acre according to the slope and the hardness of the deeper layers which have to be ploughed or broken before they can be shifted with the *karah*. These costs are for slopes of 4% to 10% but are higher than they need be owing to the Punjabi's fetish for making square fields. A pair of bullocks with a *karah* can do 300-350 cft. of earth work in a day; a coolie can do 85 cft. Costs are usually kept to a minimum by organising *mangali* teams of friends and neighbours who receive a day's food for themselves and their plough bullocks. The cost of making true bench terraces on the steeper slopes of hill land depends upon many factors including the standard of walling which the owner is prepared to build. The general standard of benching work found in the hills and foothills is so low that actual costs if quoted would tend to show that this work is cheaper than wattbandi, but this would be entirely erroneous. Bench terracing of steep land if done thoroughly either with turf walls or dry stone walls must obviously cost more than the contouring of more gentle slopes.

The cost of terracing with mechanical equipment is dealt with in para. 7. 14.

VI. *Laying out contours*

3. 38. *Levelling Instruments for Contouring.*—The simplest device is a wooden frame of any light and strong timber, say deodar, 4 inch wide ¾ inch planking, cut by a carpenter

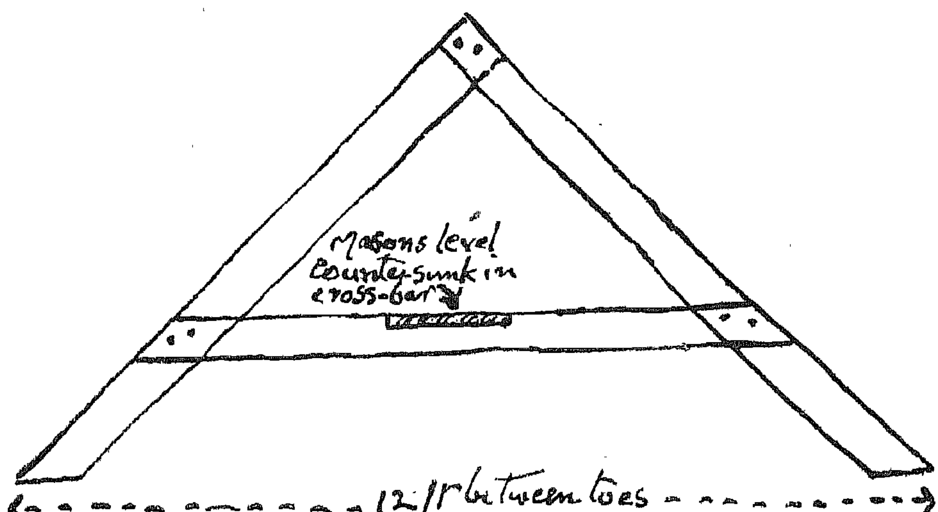


Fig. 9. LEVELLING FRAME OF ½" DEODAR PLANKS.

to a triangle with a base of 12 feet. In the cross-bar half-way between the base and the tip of the triangle a mason's level, 8, 10 or 12 inches long, is countersunk into the frame, so that the operator can observe the movement of the bubble every time he moves the frame, holding it by the tip and the cross-bar.

Drive a wooden peg at the point at which alignment is to start, say at the bank of a gully where a substantial check-dam has been built or is to be sited. Place one end of the frame against this peg and move the other end about on the ground until the bubble is central. Now, drive a second peg lightly at the further toe of the frame, pick up the frame and swing it round through 180 degrees so that the leading toe becomes the hind toe. Place this again against the new peg and move the forward toe about until the bubble is again central. Now drive a third peg more firmly, and remove the second peg. Your pegs are now 24 feet apart along the contour. Repeat this process along the ground until say 20 or 30 pegs have been located. Now look back and study the pattern of pegs.

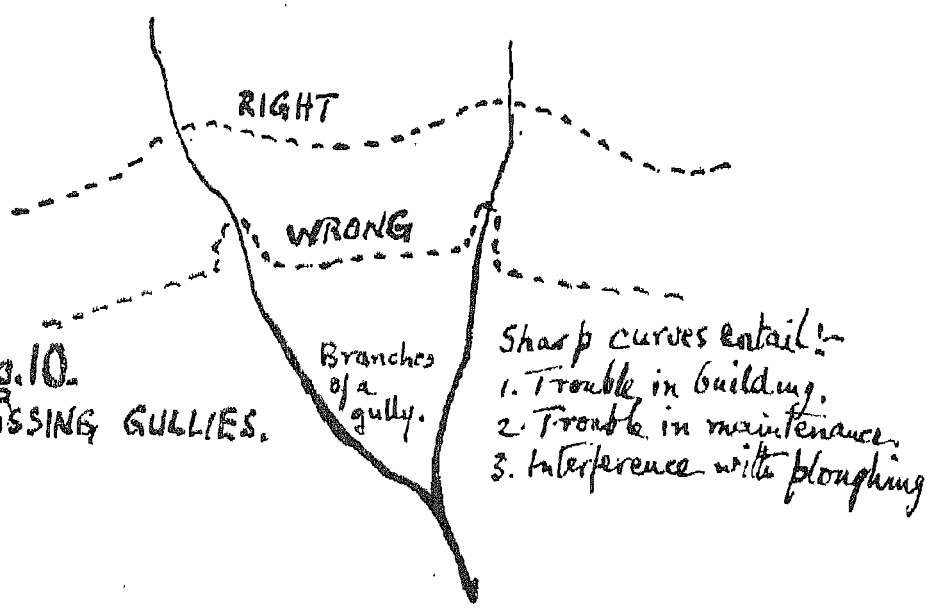


Fig. 10.
CROSSING GULLIES.

3. 39. If the pattern of pegs is to give you a very sinuous line, as it will do on a side slope on ground already seriously eroded into a complex pattern of shallow gullies, it is for consideration whether the alignment should be modified or not. If the aim is to make field wattbandi of a shape in which ploughing

can be readily done in any *direction, then the watts must* be reasonably straight, and sinuosities can be wiped out by averaging, provided that in the end the *top* of the new earthwork is finished level and is strengthened in width of earthwork at all the dips or reentrants. If on the other hand it is not proposed to make fields but to produce a series of ridge and ditch for fodder grass, fruit trees, or other trees, then better water spreading will be secured by following the sinuosities exactly, for it is only by this means that regular and complete spreading of rain or snow melt can be guaranteed. In actual practice a certain amount of averaging is justified even for grassland or afforestation, for elaborately sinuous earthwork is difficult to finish off even with hand labour and is out of the question if soil-moving machinery is being used.

3. 40. In addition to the 12 foot frame, an Abney's Level on a tripod should be used whenever possible to check the general trend of the 24 foot pegging. This is a much cheaper, handier and tougher instrument than a Dumpy or any of the theodolite type of level, but has this disadvantage that there is no compensating screw or ball and socket joint which will permit of the instrument to be adjusted after the tripod legs have been placed on the ground. In setting it up therefore care is needed to brace the tripod legs firmly into position at the same time as the bubble is levelled with the instrument set at zero. When the instrument is steady, vertically above the peg, and can be swung through the circle without altering the bubble, a sight is taken on the most distant peg or next obligatory point, taking care to use as a marker a point on the staff which is the same height above ground level as your eye is above the initial peg from which the shot is being taken. Keep the instrument set at the dead level and make the distant marker move up and down hill until you can signal him to plant his peg. Now compare the position of this peg with those which have been run out by frame at 24 foot intervals. Any discrepancy points to some mistake in the drill which should be reconciled before going any further.

3. 41. For gradients not steeper than 1 in 10 the angle representing the gradient is found from 3438|n minutes, where n is the grade—i.e. 1 in 60 gradient gives 3438|60=57.3 minutes.

3. 42. *Instructions for laying out contour terraces.*

a. In the first instance we shall have to make a reconnaissance survey of the area to be terraced, noting the classes of soil, the slopes, natural drainage channels and the like on a contour plan, and then sub-divide the area into terracing compartments between main water-escapes. The position of each outlet must

next be determined, as this fixes the starting point of your terrace bund. The slope of the ground will determine the vertical drop from terrace to terrace, and the class of soil will determine the size of the terrace drain or outlet, should one be necessary.

b. The horizontal distance between terraces is very important because this determines the area of each field and hence the amount of rain which each bund will have to hold up, see table, para. 3. 15. On clay soils which are more or less impervious on an unbroken surface, the run-off is rapid and, therefore, surplus drainage must be provided for, whereas on sandy soils, where absorption is greater, the quantity of water for removal is less and true contour bunds without outlets should be sufficient to hold the heaviest fall without any overflow drainage.

c. Make a thorough inspection of the area for gullies and decide what natural drainage channels are to be used in this and adjacent land. But do not overload these natural outlets by forcing them to carry a much heavier charge than nature intended.

d. Start at the top by selecting any plateau or hill top round which a contour ring can be marked out. Check the accuracy of this ring with an Abney level on a stand, a Dumpy level or any other instrument which will give levels correct to within 0.1%. The hill top ring should include about 3 acres on sandy land, 2 to 2½ acres on clay soils.

e. The ridge round this area should be of a cross-section of 10 ft. base, 2¾ ft. height and 3½ ft. width on top, the earth being dug from both sides of the ridge but more from the upper than the lower side.

f. When you cannot start at the top, run a diversion ditch above the first field to protect it from an accumulation of run-off (para. 3.22). When the compartment is a long one, say over 1|4 mile along the contour, it is advisable to drain the water in both directions to the gullies forming its boundaries. In the case of smaller compartments the drainage may be carried in one direction only, or the whole kept dead flat on absorptive soils. (For Table of sidewise or graded channel slopes, see para. 3. 24).

g. When rainfall is heavy or soil is a clay, locate the outlet channel first, then stake out the top terrace starting from the outlet and working back. Then stake the next one below, allowing a suitable vertical drop. If the work is to be done by a mechanical terracer or bull-dozer, put in 3 sets of pegs, the middle ones to mark the centre of the ridge and so being buried after the first machine cut. The outside pegs should be sufficiently

far apart to be left undisturbed by the machine, and will remain as a top and bottom guide line for the mechanic.

h. If staking only the centre of each *watt* for hand labour, use long stakes which will still be visible even after the bund has been built round it. Otherwise stake the bottom of each line of work.

i. Low depressions can be cut across provided the bund top is maintained at the correct height and the cross-section increased to take the extra accumulation of standing water. In crossing depressions avoid excessive height and ponding, but do not hesitate to fill in confined gullies in order to secure a good pattern free from sharp curves. Local depressions will silt up in time but regular silting to a bench terrace ideal can only be secured by keeping strictly to true contour.

j. When gullies are thus filled in, the actual bed of the gully at the point where the base of the terrace will cross it should be plugged hard with compacted earth to make this danger point impervious, otherwise breaching is likely to occur. When carrying a terrace across a gully, care should be taken to build a strong dam a little below the point of drain discharge so as to prevent scour; raise the crest well above the level of the terrace. The safest rule is to allow three inches in the foot for settlement plus six inches for rain-wash. Slopes of dams should be three to one on both sides. Take care to make a strong job throughout because the strength of a terrace is dependent on its weakest point.

k. In the choice of horizontal spacing one has to strike a balance between the desire to catch the whole of the heaviest anticipated storm and the most economic spacing which will handle a normal monsoon. The tendency is to put trenches and terraces too close, particularly where they are being dug on the better blocks of land still free from gullies and where adjoining gullies are themselves being plugged with check dams to catch and hold silt. These two operations are to some extent complementary, and a completely trenched and terraced upland will yield very little in the way of silt for the check dams below. Many instances have already occurred in which this fact has not been grasped and much unnecessary work has been paid for. When in doubt it is better to err on the side of parsimony, for extra trenches can readily be dug in subsequent years if the original lay out is still giving rise to frequent breaches.

3. 43. *Forming the bunds by grader or terracer.*—After the surveyor has pegged out the guide line, the work of the machine begins. The duty of the operator is to form a V-shaped ditch

10 to 11 feet across with a depth of one foot, running at a distance of 10 feet uphill from the bottom line of stakes and forming a hump about 18 inches in height on the lower side of the slope. With a light 7 ft. blade pulled by a D 2 it will take eight cuts to complete the trench and mound, but with heavier machines and longer blades one return trip making one uphill and one downhill cut should be sufficient in sandy soil. Diagram 11.

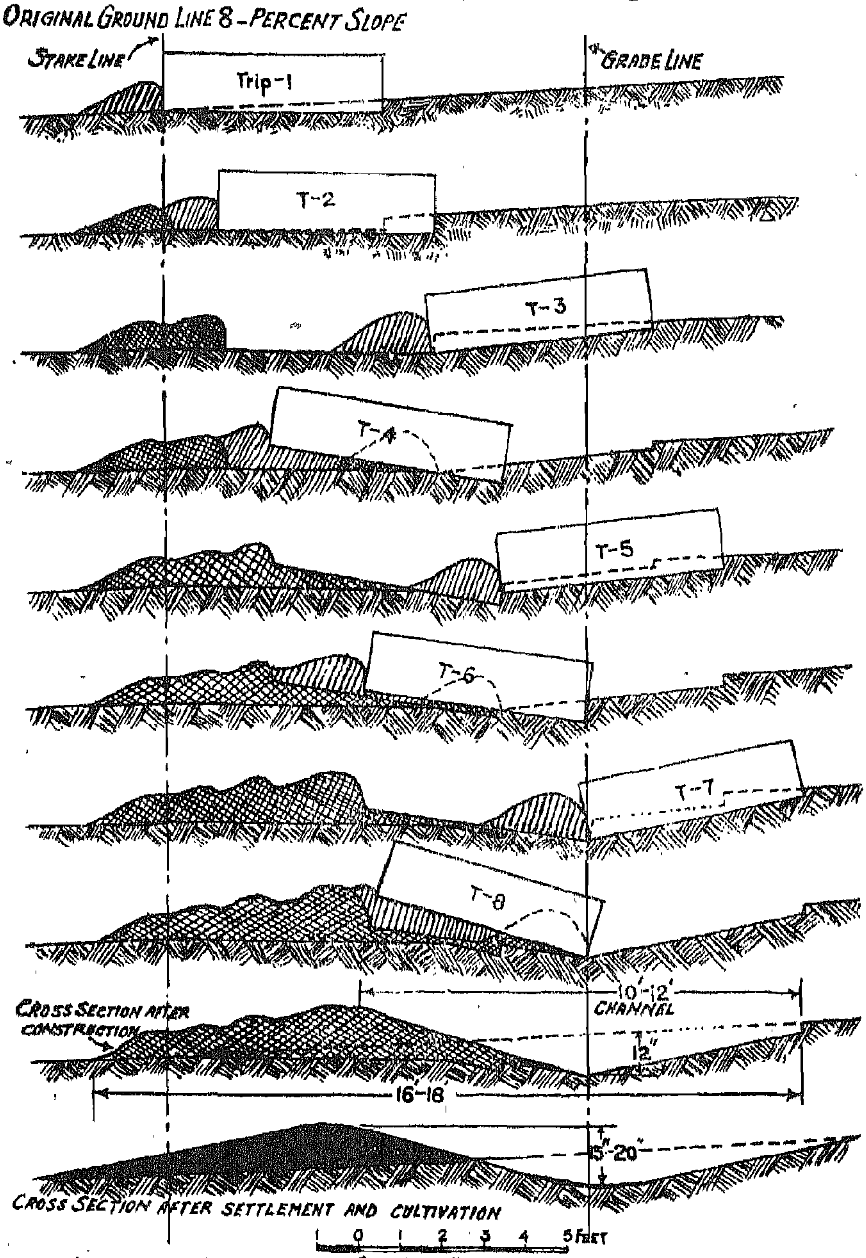


FIGURE 11

Progressive steps in the construction of graded-channel terrace in areas where small tillage equipment is used, as in South-eastern United States 7-foot blade used, working from upper side only. (Soil Conservation Service U. S. A.)

Alternatively a Killefer ditcher plough can be used to cut a trench of section

(i) 20″ deep 14″ bottom 48″ top,

or (ii) 26″ deep 12″ bottom 48″ top,

or an animal-drawn V-shaped terracer can be pulled by 2, 4, or 6 bullocks. Figure 12.

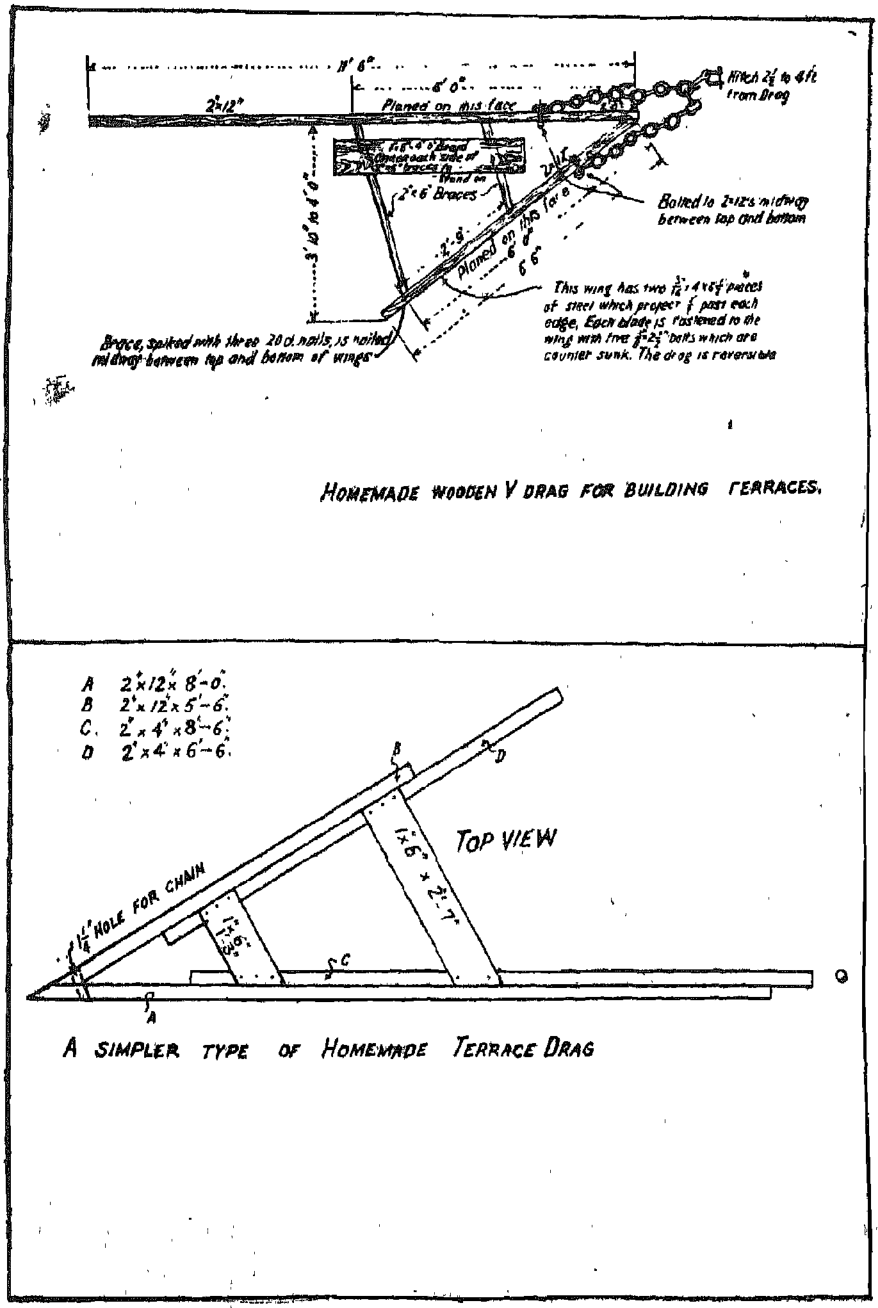


FIGURE 12

When machines are being used for terracing the final level of the top of each bund should be checked with a level and boning rod, and minor adjustments made by a squad of hand labour to pile and pack any remaining low gaps or weak points.

When the entire compartment has been terraced either by machinery or hand labour, inspect each terrace and check levels carefully and have all defects removed by cooly-labour.

3. 44. *Drainage Outlets.*—The construction of outlets for discharging water into natural gullies should also be taken in hand. If stones or timber be available the sides and bottom of outlets should be lined, otherwise fascines or pegged brushwood check dams should be used. Banks across small intermediate gullies should be strengthened and the slopes pitched to prevent breaches. In short, everything ought to be done to make the terracing as strong and as permanent as possible.

3. 45. The main drainage channels except when very steep should be protected by vegetation, and for this, *dub* grass (*Cynodon dactylon*) is now in general use by American farmers, and is so much at home throughout the Punjab that, given protection from excessive grazing, it should be able to do the job. It can also be used for the overflow channels from field to field where the drop is less than 3 feet, but the chute must be given a gentle gradient and should have no steep or vertical side walls; the whole must be shaped so that no steep fall occurs anywhere. Dub can best be established by dibbling in small pieces of root into damp soil. If the soil is very poor it would be worthwhile manuring the surface to be grassed, as this will give the grass a good start, (see para. 4. 21 c).

3. 46. For drops of 3 ft. or more between fields, a masonry outlet should consist of a single layer of bricks in lime mortar, cement pointed on the water-bearing surface, and with 1½ bricks thick for the base wall. The lip should be a few inches above the general level of the field so as to ensure that it silts level. The wing walls must be substantially higher than the lip, and the earthwork of the watt must be maintained a good foot higher than the top of the wing-wall. Wherever there is any fear of scouring at the base of the water-way, a stilling pool should be provided by laying a double layer of bricks across the path of the flow so that a pool is formed for the water to fall into at the foot of its descent over the fall.

3. 47. The building of brick outlets should be discouraged as far as possible, because it should be our object to teach the cultivator to control the movement of water by natural means so far as that is possible for any given set of conditions of slope,

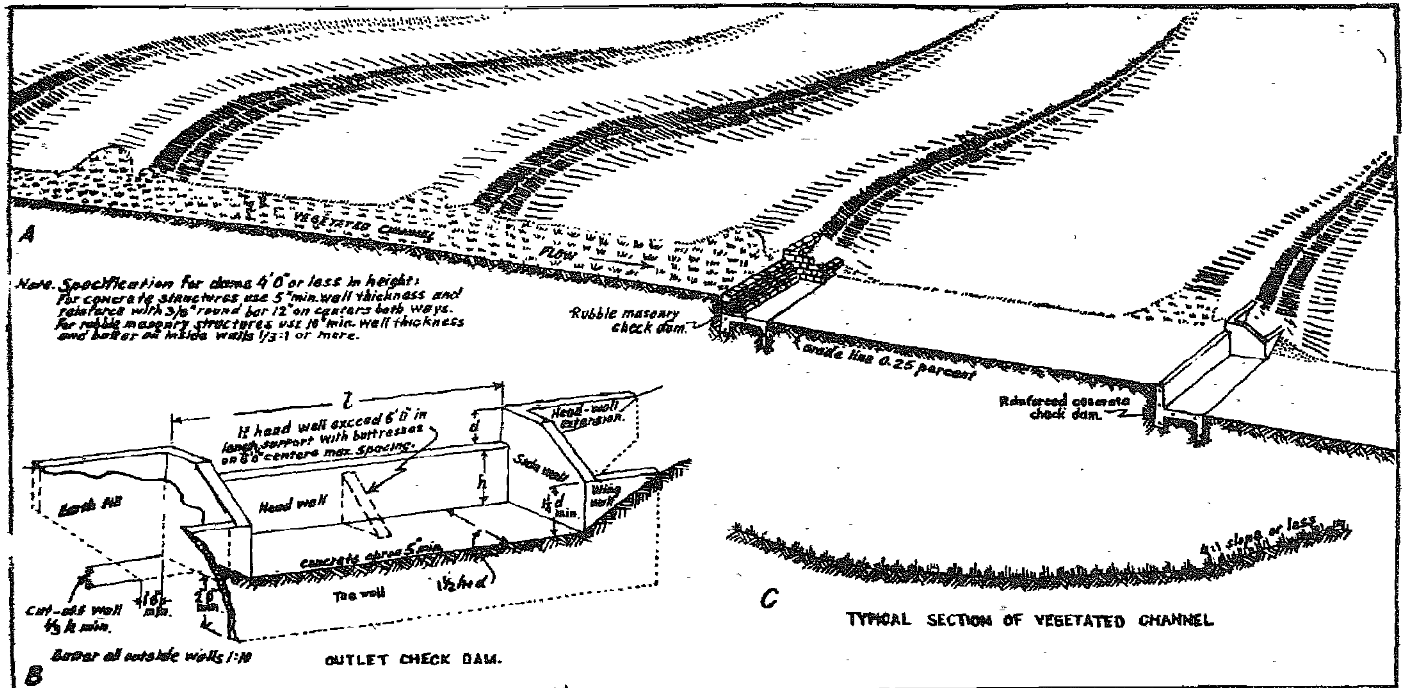


FIGURE 13

A Terrace-outlet channel protected from erosion by a combination of vegetative and mechanical measures The sectional view in the upper part shows vegetative protection in the upper reaches of the channel and check dams in the lower part. The construction details of the check dams and the cross section of the vegetated channels are shown in the lower part of the Illustration. (Soil Conservation Service U. S. A.) Paras. 3.45 and 46.

soil, and catchment. They are however a good investment where fields are cutting back and gullying to an extent that the cultivator unaided can no longer maaintain his watts. (Figure 13).

3. 48. *Operation of Section 5A of Chos Act.*—The full text of the amended Chos Act is given in Appendix II. Section 5A is not yet operative, but it is hoped shortly to have it applied under a general notification making it applicable to each revenue estate. The procedure will thereafter be as follows:—For the area concerned a warning public notice is issued under Section 7 by the Deputy Commissioner with the previous approval of the Financial Commissioner Revenue, and laying down a reasonable period within which the owners should do the necessary work themselves. After the lapse of this period, and where it has met with opposition from individual owners or tenants who object to carrying out the instructions re levelling and|or *wattbandi,* our Soil Conservation staff will prepare a list of *khasra* field numbers thus affected and submit them to the Deputy Commissioner who will issue a warning notice under Section 7A stating that the work will be done by government and the cost, up to 10 times the land revenue of the individual's estate or holding, will be recovered from the owner or tenant.

Chapter IV.

THE PREVENTION OF EROSION IN PASTURES BY PROPER GRASS-LAND MANAGEMENT.

4. 1. *The Grazing Problem.*—The subject is dealt with very exhaustively in Chapters VII and VIII of the Report of the Royal Commission on Agriculture 1928 and no attempt is made to minimise the difficulties of the problem; in fact both the difficulties and the importance of the subject are stressed in the following sentence:—

"We are well aware of the difficulties likely to be met with in practice in getting owners of cattle to adopt more rational methods of utilising the diminishing grazing areas of India, but the poverty of so large a proportion of the breeding herds of the country is such a serious handicap to the improvement of agriculture, and the management of the available grazing lands is so bad, that a great effort to alter existing conditions is necessary, and is indeed long overdue."

These words were written 18 years ago, and there appear to be two very cogent reasons why the problem should be tackled in earnest without any further delay. The first is that what was described by the Royal Commission as "pressure on the land" from an increasing human population is a matter of still greater concern since the issue of the latest census figures, which show a 10% increase in the last decade. The demand for cultivable land is, therefore, certain to increase. The second reason is that the provision of better grazing facilities is a necessary adjunct to any compaign for the improvement of India's cattle population, particularly that most essential item, the working bullock.

4. 2. As regards British India, the Royal Commission points out that of the total area of land about 20% of it is administered by the Forest Department and 45% is classified as "cultivable waste, or land not available for cultivation", and it makes the recommendation that in both these areas the classification should be re-examined with a view to providing better grazing facilities for India's livestock. Although the percentage of land under the Forest Department in the Punjab is only 6%, this argument carries even more weight owing to the correspondingly greater area of uncultivated waste in the hands of the

villagers themselves. With reference to the area now administered by the Forest Department, the Commission states: "The ideal to be aimed at in all provinces is to distinguish between land which is suitable for the growth of good timber trees or for fuel plantations and land which is suitable neither for timber, fuel plantation nor for ordinary cultivation, but may possess possibilities for development as fodder reserves and grazing grounds". Action on these lines has, of course, already been taken in some districts such as Hoshiarpur and Kangra where societies and village forests have been encouraged on a large scale, but the western districts contain over 2 million acres of unclassed forest which is under no sort of management whatever. (A. A. Khan in *Indian Forester* for May, 1946).

4. 3. It appears that the Commission contemplated that such grazing lands, after reclassification, should be administered by a special branch of the Forest Department as a demonstration of what can be done under scientific control, but at present the question of reclassification is being dealt with piece-meal as each society working plan comes into operation. In regard to these forests classed as grazing areas the Commission states: "Because of their small commercial value and also because the important forests give scope for all the energies of the existing forest staff, little attention has been given to the development of the second type of forest property. Nor do we think it likely that it will ever receive the attention that should be given to it unless it is placed under the management of a division of the Forest Department directly responsible for its development". To follow this to its logical conclusion, all such land should come under the Soil Conservation Circle as being the unit of government most directly concerned with the reclamation and improvement of government owned waste.

4. 4. Turning now to the areas classed as "cultivable waste" and "land not available for cultivation" but belonging either to individuals or to communities as village *shamlat*, the Commission remarked:—"We think it likely that within these vast areas there could be found much land which, although unsuited for commercial afforestation, might, if placed under the charge of a minor forest division, be used to grow fuel and provide better grazing than it now does." (The most logical organisation for management of such land is obviously the Co-operative Society.)
The Commission realised that to effect any improvement, time and money would have to be spent and a good deal of close study given to the problem by officers specially selected and trained for the purpose, and they conclude their remarks with

the statement: "We are satisfied that a share of the attention which has hitherto been bestowed on the valuable section of the country's forest property should now be spared for, and concentrated on, the problems presented by that portion of the land now regarded and treated as waste."

Much discussion has been reported on the subject of "Forest Grazing" in past Silvicultural Conferences, and reference should be made to valuable papers under this head in the printed proceedings of the All-India Silvicultural Conferences of 1929, 1934, 1939, and 1946.

4. 5. *Over-grazing.*—The grazing problem of the Punjab has been dealt with fully by Sir H. M. Glover in his book "Erosion in the Punjab; its Causes and Cure" and it is not proposed to repeat or enlarge upon his descriptions of the amount of damage done in the Punjab foothill districts. The facts are sufficiently well known to government and its officers, though possibly not yet to the general public, nor to the politician whose natural inclination probably is to obtain additional grazing privileges for his constituents. It is proposed here to deal more fully with the cure than the cause of erosion in the grazing lands and more particularly those phases of remedial action and reconstruction that fall within the Punjab's Five-Year Post-war Plan (Appendix I). Some statistics may however serve to place the problem in its correct perspective as forming a very large part of the erosion problem as a whole.

4. 6. The position is complicated because of other and equally serious misuses of the land which blur the effect of over-grazing. In the northern Punjab and in the North-West Frontier Province, for instance, the demand for cultivable land has led to the breaking up of much land too steep for terracing to be worth while; the standard of cultivation of Gujars and other nomadic graziers taking up a permanent and settled abode is lamentably low and wasteful of soil; insufficient fields for food crops justify the keeping of large flocks of donkeys, pack bullocks or camels to eke out a livelihood as carriers; failure to demarcate and reserve fringes of forest or too generous admission of grazing rights in forest reservations are responsible for serious retrogression in forest types as well as for complete disappearance of the scrub forest or thorn bush which so often adjoins or replaces true grassland.

4. 7. The Punjab and the N. W. F. Province between them produce a total of 70 million tons of fodder from cultivated land (R. L. Sethi's Note on Cultivated Fodder; *I. C. A. R. Proc.* 1940); ⅘ of this is from fodder crops as such, namely *chari*,

guara, senji, methi, shaftal, jowar, berseem, etc., and the balance is straw from grain crops such as wheat, barley, *bajra*, rice, gram, etc. Taking the cattle population as 3 million buffaloes and 32 million cows and bullocks, requiring respectively 80 and 35 lbs. of fodder per day (a very conservative figure in every way) and leaving out any mention of sheep and goats and transport animals which all compete for the available fodder, these cattle require 220 million tons of fodder a year. The difference between 220 and 70 million tons ought to be coming from the grassland of the province, but is not doing so because of the universal curse of over-grazing, under the weight of which our grass-lands are deteriorating rapidly into bare screes of stones or of ever deepening gullies. Under such circumstances insistence upon a detailed grass-land survey, such as recommended by the International Grassland Congress of 1937 as being of primary importance, appears to be really of quite secondary importance when the whole countryside is already reduced to a dead level of inefficiency. A more practical approach would be to tackle every possible phase of reduction of livestock combined with the improvement of pastures and the upgrading of livestock.

4. 8. The position is governed by what is politically possible rather than by the scientific approach. The effect of religious antagonism was well illustrated in a recent Punjab experience. The Kenya Government allowed Leibig's to open a canning factory, and guaranteed them an annual minimum supply of cattle carcases; this would go a long way in itself to reduce the scrub herds and make a profit out of some at least of the surplus animals. A similar project in the Punjab was to form part of a large cold storage development for fruit and vegetables as well as meat. The scheme was thoroughly worked out and opinions obtained from various quarters that it would not arouse any religious sentiment, but as soon as it had been launched it became the centre of an agitation against the slaughter of animals and had to be dropped. Possibly in the western districts where religious feelings are not so actively susceptible, it might be feasible to introduce small plants for the rendering of carcases into tallow which is used for soap manufacture, and cracklings which is used as fertiliser and cattle food. The process is simply that the hide is removed and either cured in salt for the tanneries or sold dry for glue manufacture. The rest of the carcase is treated in a pressure boiler to extract the maximum of tallow fat, and the remainder is ground to a powder which can be used in the same way as artificial manure or for feeding to animals. (*U. S. D. Agric. Circ. No.* 63, 1934: Conservation

of Wastes from Small Scale Slaughter of Animals, by G. P. Walton and R. F. Gardiner).

Many forest officers in the drier tracts are so obsessed with the over-grazing problem and its terrible reactions upon the community as a whole that they have given up hope of ever achieving reasonable conservation and are reconciled to the idea that the community is headed for destruction. The reserves, already much too small, are being whittled down to meet every fresh political agitation. Grants of fresh grazing land or grazing concessions merely stimulate a further increase of stock, and in a short time the new grounds are destroyed or reduced to the common level of eroded desolation. But the universal antipathy towards stall feeding is based on the fact that a man can hardly cut enough grass for 3 cattle whereas a small boy can look after a grazing herd of 100 head.

4. 9. Where executive orders for the reduction of herds cannot be obtained, the best line of action appears to be to get the stock owners interested in improving their beasts. There are many ways of doing so, but the most promising appears to be a combination of painless castration and the elementary requirements of grading up the local stock with the introduction of rotational grazirg and the replacement of grazing by grass cutting. Lord Linlithgow's efforts to encourage the presentation of stud bulls by public-spirited individuals met with a considerable measure of success, but the limiting factor proved to be the difficulty in feeding them properly unless some endowment was made for this purpose. Our future programme should include all or as many as possible of the following items:—

4. 10. *Summary of Pasture and Livestock Improvement Items.*

(a) encourage closures, either complete or rotational—detailed notes follow.

(b) partition of *shamlat* (common land) to individuals has been only locally successful. In Jhelum Salt Range only 10-15% of the partitioned land has been improved.

(c) co-operative or panchayat management of waste land,—see Chapter XIII.

(d) replace grazing by grass cutting and stall feeding; this can best be done through the medium of co-operative societies.

(e) encourage reduction of numbers by humane killing, improved grading of hides, disposal of carcases by making bone meal. See para. 4.8 for previous discouraging results; but equipment is available, somewhat similar to a portable sawmill, for converting carcases into bone meal which can be used for manure or cattle feed.

(f) taxation of animals surplus to bonafide cultivators' needs is being applied in Kangra but has not yet had much effect.

(g) control migratory movements and reduce percentage of goats in flocks by favouring sheep under *tirni* tax; government has admitted the need for control in important catchments such as the Uhl.

(h) grassland improvement by contour ridging, contour ploughing, wattbandi, water diversion, reseeding, deep ploughing, kiarabandi etc.; fodder production from reclaimed cho beds and by flood farming; mixed crops of grass and wild legumes.

(i) get hay crop harvested early before it dries up; as the hay has to wait until autumn sowings are finished, it appears better to improve the grass to such an extent that it keeps green longer into the autumn.

(j) develop cut grass marketing and the baling of hay—see para. 4.25 regarding baling costs.

(k) scrub forest improvement by pruning lower branches and thinning undesirable bush growth; elimination of *Lantana* and other weeds; apply ecology to choice of species for sowing (*Punjab Forestry Notes No.* 10, 1945).

(l) encourage and publicise value of green fodder and of cover crops on bare fallow; this can only be done with the close co-operation of the Agriculture Department.

(m) encourage composting of manure to make it go further; this again is more a matter for the Agriculture Department.

(n) save liquid manure for dressing on grassland; has proved invaluable in Europe but will be difficult to establish in the Punjab.

(o) save by silage any excess production of green crops; this again is the function of the Agriculture Department.

(p) application of artificial manures to improve grass output and quality; wartime restrictions on movement of chemicals being now removed, we should be able to demonstrate this; costs must be accurately kept in all cases.

(q) planting of fodder trees and emergency forage crops such as pulping of *Agave* & prickly pear; introduce spineless cactus.

(r) rotation of tree lopping: para. 4. 26; lopped fodder yields and food value to be analysed for all regions but particularly for the desert fringe.

(s) castration of surplus scrub bulls with two or more teeth; Director Civil Veterinary Service has undertaken to train nominees from societies.

(t) castration of surplus male goats and rams; segregation of male goats from flocks can best be introduced once selected staff of societies have been trained to livestock work, but Gaddi societies may take long to establish; substitution of goats by sheep, and sheep breeding to be pressed forward rather than complete elimination of both goats and sheep, but they must be a first charge on the land and not added to over-grazing by cattle.

(u) introduction of pedigree bulls and rams, and cows of superior milking strains, depends upon availability of suitable animals and can best be undertaken by cooperative societies under the advice of the Veterinary Department.

(v) survey of grasslands and of erosion intensity in them vide chapter XIII.

(w) selection of local and introduced grass strains; better seed collection methods; establish grass gardens; determination of palatability of grasses and deficiencies of pastures; samples from demonstration closures can be analysed by the Agricultural Chemist, Lyalpur.

(x) introduce "licks" of salt or chemical blocks containing deficient minerals; first ascertain what are the chief deficiencies by sending Agricultural Chemist forage samples then order blocks from I. C. I. or other chemical suppliers.

(y) improve watering arrangements by multiplying dams, tanks, ponds, wells etc., and use of pumps; vide Chapter VIII.

(z) provision of cheap and effective fencing material, both for permanent divisions and easily transferred temporary enclosures.

This may seem a formidable list, but when it is realised that Kangra district, for example, has a million head of livestock, for which the grazing available is 900,000 acres of forest land and 1,200,000 acres of uncultivated *malkiat* (private holdings) for a cultivated area of 562,000 acres it will be realised that such uni-lateral action as the raising of the cattle tax is in itself unlikely to have much effect. We require "combined operations".

4. 11. *Permanent Closures.*—Geologically the whole of the Siwalik foothills and much of the Salt Range upland is so unstable that any form of grazing must inevitably lead to disaster. Merely by letting cattle graze for a few seasons, deep gullies appear, causing ruination of the natural grassland by destroying the underground moisture balance. The only hope of making a better use of such land is to eliminate grazing altogether, and persuade the people to harvest the grass as hay and feed their cattle at the foot of the hills. In 1902 a special Land Preservation (*Chos*) Act was enacted in order to preserve this land. Originally the Siwalik villagers were not willing to allow their lands to be closed to grazing but now they are happy to allow this to be done as they are able to sell off their surplus cut grass. The Chos Act now applies to the whole province and the experiment of these closures, at first compulsory, latterly voluntary, is now being followed up throughout the Punjab soil conservation districts by means of propaganda and publicity amongst the people, the object being to obtain closure by agreement. Under the Chos Act closure can be notified provided a majority of the owners of the land apply to government for closure. Section 38 of the Indian Forest Act can also be used but 2|3rd signatures are needed. The aim has been to persuade a sufficient number of people to apply for closure, and having got their application, to gazette a notification that such and such parts of the land will be closed for a definite period of grazing. There are two types of closure under the Chos Act:—

(i) partial, by eliminating goats and camels (section (4), & (ii) total, by elimination of all animals (section 5), but experience has shown that partial closure even over a period of 35 years does not stop erosion. The aim therefore is to teach people that they get the best value from their land by keeping

the cattle out entirely and cutting grass, using what they need and selling the rest to surrounding villages which have no grasslands. The cut grass from the Siwaliks has been selling as far afield as Patiala, Jullundur and in places across the Sutlej river, and has also been of help to the eastern districts of the Punjab at times of drought.

4. 12. *Rotational Closures.*—The earliest record of rotational grazing in India, apart from the long closures of 10, 15 or even 20 years to obtain forest regeneration, is recorded by Dr. W. Burns in the *Indian Forester* of December 1931 for the Bhamburda area near Poona. He describes the result of a 5-years programme of low contour ridging with stones and rotational grazing to compare the relative efficiency of annual closure until after hay was cut and annual closure until the grass was mature. The result showed clearly that degraded scrub areas recovered remarkably under either treatment, and were able to carry one animal to 2 acres without difficulty from July to December, but they had to be stall-fed with grass cut from a closure during the rest of the year. Dr. Burns' recommendation was that a large herd should be grazed in one restricted place which should be changed frequently as soon as the area showed signs of having been over-worked. In the absence of fencing, penning must be done by the herdsmen. Blocks of salt for licking can be used to attract the animals into the less palatable patches so that they also are fully utilised.

Any rotation must aim at taking full advantage of the rapid grass growth during the monsoon period; even in the arid areas where the monsoon is very weak it is at this season that the grass makes its best growth.

4. 13. The simplest rotation which secures a long rest for each block in turn therefore appears to be as follows, R, W, and S standing for Rains, Winter and Summer. I am indebted to Mr. A. E. Garland for this diagram, which was previously reproduced at page 46 of my "Land Management in the Punjab Foothills", 1941. Figure 14.

This pattern secures that each block in turn enjoys a 16 months closure starting with C, then B, then A; each block also has a shorter respite after having been grazed in winter and summer, but the main point is that each block can mature a crop of grass and have that crop's seed sown and sprouted before being again opened.

Within this general framework it should be possible with the aid of barbed wire or electric fencing to keep the cattle concentrated for brief periods on a certain area which will benefit by the concentration of the dung and urine they will receive.

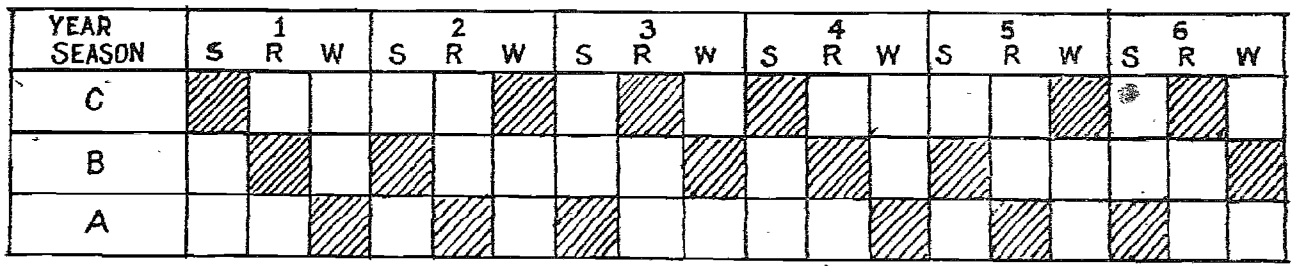


FIGURE 14

Grazing Rotation in 3 periods of 4 months each. Para 4.18.

4. 14. The application of the term "rotational grazing" to the 15-year closures of the Kangra Valley and other working plans of the past is a complete misnomer in the agricultural sense. This long period has arisen in our forest working plans to meet the need to establish tree regeneration safe from browsing animals,—and it is still indeed very essential to secure this protection,—but a period of 10 or 15 years with one block closed and one open the whole time does not fall in with the livestock farmers' idea of rotation which is in terms of days or weeks rather than of years.

In the *usar* salt lands of the U. P. which had been somewhat improved by cultural work and partial closures during previous years, rotational as opposed to periodic closures gave the following results:—

(i) the grass produced by monsoon closure is unaffected by *normal* incidence of grazing during the following winter, (Heavy overgrazing will however damage the turf seriously).

(ii) rotation of one month's grazing, 3 months' closure, throughout the year led to deterioration owing to one of the open months being in the monsoon and therefore causing damage by puddling and uprooting from muddy soil, particularly where a lot of animals are concentrated for a short time, as is a feature of short rotation grazing.

(P. C. Kanjilal in *Leaflet* 12 *of Forest Dept., U. P., July*, 1945).

4. 15. A series of grass plots were established at Nurpur Kangra in 1937 by sowing various species pure and in mixture on a trenched slope. No weeding or cultural work was done so that in the course of a few years all the plots merged into more or less of a mixture of species with *dub* grass disappearing and *sariala* (*Heteropogon contortus*) and *Apluda aristata* becoming dominant. The yield of cut grass was very poor in the first two years, averaging 25 maunds and 35 maunds, owing probably to the infertile clay subsoil (which had been previously reduced by sheet erosion and further aggravated by exposing more subsoil by deep trenching). The yield did however rise steadily until it averaged 82 maunds per acre of hay in the 5th year, after which it fell off again, as one would expect on this type of clay slope without any further cultivation or manuring, (*Punjab Forestry Notes No.* 10, 1945). This falling off after closure is reported as a consistent feature in the elaborate rotational closure experiments conducted by Mr. K. P. Sagreiya, Central

Provinces Forest Department. In the case of their good and medium grasslands it is only 3-4 years before deterioration sets in. It is on such ground that intensive grazing on rotation for only a few days or weeks, where cattle are penned and the ground thus manured, should give good results. The same applies to much of our Punjab grasslands once they have been given a chance of recovery.

4. 16. The actual operation of rotational grazing must be kept under the strict control of someone who really knows the needs of the animals, and the capacity of the grass to recover from short spells of heavy grazing. He must be left free to manipulate the herd as he thinks fit; there is no profit in a hard and fast schedule of dates for changing paddocks, particularly if this schedule is prepared from an office calendar without reference to the condition of the grass. One year you may have an early flush of grass, another year growth may be slow or late. Paddocks must be kept reasonably small, say 20 acres, and the herd divided into groups of 100 or so. There should be a reserve of extra paddocks which are normally for cutting hay but which can in bad years be used for grazing to avoid damage to the usual rotational ones. In areas where over-grazing has so reduced the value of the fodder crop that *Cassia tora* and *Adatoda vasica* have ousted the previous grasses, the immediate introduction of rotational grazing will not help much, and in such cases cultural operations of some sort to increase the stand of fodder grasses are an obvious preliminary step.

4. 17. *Co-ordination of Research with Actual Pasture Improvement.*

The improvement of grazing practices, the upgrading of cattle, the introduction of stall feeding, all depend upon the grass we can produce from waste lands, and this phase of soil conservation must in future be given a much more prominent place than it has received in the past. We should not be satisfied with quoting figures of increased weight of fodder grass cut from closures, but must see that hay produced from them is the best possible for any area.

Several efforts have been made in the past to secure funds from the I.C.A.R. to cover the cost of grassland improvement experiments, but the only one so far sanctioned is for Hissar district. This has been prepared by Director of Agriculture for a number of villages of Hissar district outside the Government Livestock Farm. As it is unlikely the I.C.A.R. will be prepared to duplicate this in any other Punjab district we must push ahead with our own local demonstrations. Pending

appointment of a provincial Land Utilisation Board we ought to consider detailed projects, which can in due course be put up to the provincial board by districts to show how far improved practices for control have actually been determined and can be operated on local waste land.

Under the postwar development programme certain areas are to be selected for *intensive work in agriculture* and other uplift, preferably those areas for which we already have catchment or regional working plans prepared or under preparation. Whatever grass improvement is feasible in these tahsils will be included in the Forest Department working scheme for the area. Grass improvement research should also obviously be taken up in those areas and a grass garden with sample plots of good local and likely introduced grasses should be established at each centre.

4. 18. *Perennial Grasses and Soil Structure.*—The following account of the action of the roots of perennial grasses upon soil structure is extracted from the Journal of the American Society of Agronomy for 1937, pp. 89-90. The author is Dr. Richard Bradfield, a leading physical chemist, who explains earlier in the same paper that he himself remembers as a boy ploughing virgin prairie sod on a farm that is now on the fringe of the "Dust Bowl". The soil condition he then noted, and now describes, is one which practical farmers should strive to reproduce in their over-cultivated or overgrazed lands with the aid of suitable grasses:—

"Grass roots are so numerous that in a well-established sod they are seldom over 3 to 5 millimeters apart. Each root represents a centre of water removal. As water is removed the small *fragment of soil between the roots* shrinks and is blocked off by the roots. The pressure developed by the capillary forces, compressing the granule from all sides, is great; in many soils it reaches over 5000 lb. per square inch. As a result these granules become quite dense, their *apparent specific gravity ranging from* 1.8 to 2.0. The total pore space inside them is small and the size of the pores is very small. Water moves into them slowly, but is held firmly. The pores are so narrow that they are easily completely sealed by capillary water and as a result the ventilation of the interior is poor. Consequently reducing conditions frequently exist in the interior of the granules simultaneously with oxidizing conditions on their surface. This often causes a migration of substances which are more soluble when in the reduced form to the surface of the granules, where they are oxidized and deposited. This deposit serves as a cement and helps to stabilize the granule."

"In forcing its way through the soil many cells are sloughed off the living root and serve as food for bacteria. Eventually the roots die and are decomposed in situ, forming a humified, often water-resistant, coating around the granule. The marked difference in colour between the surface of such granules and their interior is evidence of this. In the strongly granulated soil practically the entire mass of clay and silt particles are clumped together in these water-stable aggregates. As a result there are two fairly sharply defined groups of pores in such soils, capillary pores between the granules and non-capillary pores which are relatively large. Such a soil has a permeability approaching that of sandy soils combined with a storage capacity of the heavier-textured soils."

Grass sod is effective in building up a soil profile partly because of its desiccating action which produces conditions of alternate wetting and drying, and thus combined with the action of humic acids upon the C horizon and underlying rock, helps to build up also from below. Stimulation of micro-bacterial action in soil causes a better aggregation, probably through the cementing action of fungal mycelium, and hence reduces its erodibility.

This is the structure which perennial grasses tend to develop in soils. Such soils provide optimum growing conditions for most crops, hence the value of grass sod as a means of building up fresh agricultural fertility on a rotational basis.

It is not known how many seasons' growth are required to produce the optimum structure. The major part of the work is probably done in the first few years of growth of the sod. In the case of the desert fringe recommendation of *sirkanda* grass as a means of building up a humus content, 4 years under grass then 4 years cropping has been suggested (para. 12, 23-25).

4. 19. *Food Value of Grass as a Hay Ration.*—Work by Dr. P. E. Lander and L. C. Dharmani at Lyallpur on the chemical values of Punjab grasses has shown that many of the foothills grasses when cut for hay are incapable of producing a "maintenance ration" owing to deficiencies of nitrogen, phosphorus and calcium in both the soil and the grass. ("Indian Grazing Conditions, and the Mineral Contents of Some Indian Fodders". *Imp. Coun. Agr. Res. Misc. Bull.* 16, 1937 and *Ind. Jour. Vet. Sci.* 1931). This is partly due to the nature of the ground because the foothill slopes, even when reserved for grass in the monsoon, are trampled and eroded the rest of the year; it is also partly due to the very quick drying up of the crop in the autumn, the usual grass-cutting season being after the autumn ploughing, by which time the grass is bone dry and practically worthless as fodder,

but nevertheless universally used as such. The cures for these deficiencies lie in (a) improving the grassland, and (b) supplementing the fodder ration.

The prevention of erosion and the conservation of a meagre and irregular rainfall would rejuvenate the grasslands to an amazing extent, as has already been proved in grass gardens and erosion control demonstration areas. The main point is to increase seepage, and this can best be done with some form of contour trenching. The application of the wattbandi, or contour ridging principle to grasslands as well as to ploughed fields is the obvious solution.

Grass samples collected from a small treated area at Nurpur in Kangra district showed a definite improvement over the ordinary hillside, thus illustrating the rejuvenation which takes place even in the space of two years respite from over-grazing, through a reduction in fibre content and an increase in protein and fat values,

	Fibre.	Ash.	Fat.	Protein.
Grass from grazed area .	39.24	9.75	1.39	5.55
Grass from 2-years' closure ..	37.94	7.73	1.71	6.32

To supplement the fodder ration there are two ways open, manuring the pastures or providing salt blocks containing a ration of the missing essentials for the animals to lick. The latter appears to be the cheaper and more direct method and has much to recommend it. My own view is that many of these apparently deficient grasslands will produce a grass with a much higher percentage of the essential chemicals as soon as erosion has been prevented and the normal interactions of a thicker plant cover upon the underlying rock have been allowed to resume work, particularly if helped by contour ridging and application of liquid urine saved from cattle-shed floors.

In the Kangra valley an interesting piece of public health research by Dr. Dagmar C. Wilson on the prevalence of deficiency diseases such as osteomalacea and pellagra has shown that the cure is in better green food and milk. If the main articles of diet are themselves deficient in the essential chemicals it would appear as if the only relief can be in supplementing the human diet from outside, but here again the so-called deficiencies are caused largely through the misuse of Nature's own methods of growing crops and the vicious circle can only be broken by insisting upon the conservation of plant growth and water supplies. These will yield a complete ration for a few sleek stall-fed cattle, and the conservation of firewood will save the manure for the

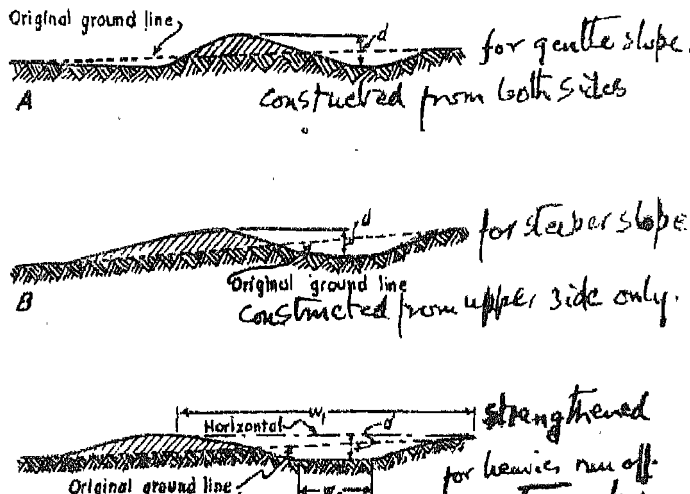
fields so that they in turn will yield food crops full of the essential foodstuffs.

4. 20. *Grass Cultivation in Erosion Control.*—We have seen that untended fallow, either bare or allowed to become weedy, is a fruitful source of soil loss, and we have also found that our search for suitable leguminous plants to grow on fallow fields has not yet produced the complete answer (para. 12.40). The alternative appears to be to develop grass as a crop which will take its place in field rotations on land still under cultivation. as well as a means of producing a permanent cover on fields which have been abandoned by the cultivator. All through the mixed scrub forests of the drier foothills of India are to be found patches of abandoned fields which have failed to produce a plant cover thick enough to check further deterioration. Their condition emphasises the fallacy of our *laisser faire* tradition of leaving it to nature and her slow ecological processes. The correct treatment is to establish a grass crop by the cheapest practical means; the trees will follow naturally.

Natural grass-lands entirely undisturbed by man and left to nature are few and far between, but in both the plains and foothills they consist of scattered savannah or bush jungle with lighter and poorer grasses in the open spaces and a heavier crop of coarser grasses around the base of each tree. In choice of species for fodder those grasses which grow in the open may in theory be better than those around the tree base, but in practice the hay yield is from the latter because they keep longer green and still have some food value in them when cut in the late autumn, whereas those in the open are so dried up as to be devoid of any food value. To improve this condition, we must pay more attention to the requirements of *grass as a crop.*

The most successful growers of grass in India are the Military Farms Department and the Hissar Livestock Farm, and their success is based on attention to soil conditions. Like all other plants, grass requires plant food, moisture, and aeration of the soil. The poverty of our hillside clearances may be due to some extent to the fact that the top-soil has all gone and that the remaining subsoil is poor in nutrients, but lack of water and of aeration are much more potent factors, so the chief remedy lies in contour ploughing or contour digging which will disturb the compacted soil to a greater depth than is possible with the country plough. For paddock improvement in New South Wales contour furrows 9″ deep, 2 ft. wide and 24 ft. apart on a slope of 1 in 12 are recommended. (*Jour. Soil. Consr. Serv. N. S W.,* Jan. 1946). Figure 15.

Fig. 15. CONTOUR FURROWS FOR PADDOCKS



Adapted from H H Bennett's Soil Conservation by courtesy of McGraw Hill Co.

The better the growth conditions we can give it, the longer will be the growing season of the grass into the autumn. We cannot alter the months in which the villager can cut grass between his other essential crop work but we can ensure that the grass is as good as possible at the time when he can spare to cut it.

Bare eroding surfaces and land once ploughed but now overgrown with weeds can only be reclaimed by ploughing or soil working. Grass as a crop demands all the ordinary plant foods, but in the reclamation of degraded scrub it is normally not feasible to do any manuring, and the best that can be done is to include some useful legume such as *guara* (field vetch, *Cyamopsis psoralioides*), sowing it either in mixture with the grass seed or as a pure crop to give quick ground cover that will be of immediate use as fodder. It will not stand prolonged drought so should be sown immediately the rains start; pure crops at the rate of 25 lbs. of seed per acre: in mixture with grasses, much less, say 10 lbs. This is the only one of the commonly irrigated fodder species which is likely to produce a good yield as a *barani* crop.

4. 21. The following notes on the common fodder grasses are based partly on Military Farms and Hissar experience:

(a) *Anjan, Cenchrus ciliaris* Linn syn. *Pennisetum cenchroides*); and *dhaman*, (*Cenchrus biflorus Roxb*).—These are separate species, the former with a dark rough flower and the latter with a lighter and more hairy inflorescence, but have the same fodder value and the vernacular names are often interchanged. They do best in a regular and fairly heavy rainfall, but *anjan* persists in very arid conditions if sown on deeply ploughed land. In Hissar with an erratic rainfall of 14" it has persisted through several very bad years of short rain.. It was first sown in pastures made by ploughing with a steel plough to 6' depth and throwing up small contour ridges every 15-20 yards, by making a double turn with the plough to place two furrows back to back. In good years it is harvested and in poor years grazed, but the grazing must be strictly controlled if the grass is to persist. The combination of tree shelter-belts along contour bunds, and of *anjan* pastures flourishing on what was previously a wind-swept bare desert, together form the basis of the Hissar Livestock Farm's highly successful counter-measures against wind erosion. It should be visited by all soil conservation students.

(b) *Palwan*—in the U. P. *janewah*—(*Dicanthium annulatum* Stapf. syn. *Bothriochloa pertusa*, A. Camus.) is the best fodder grass in the U. P. but falls off in value and quantity with erratic rainfall, though it is palatable all the year round and has a persistent flowering habit. Military Farms admit seven varieties all known as *janewah*.

(c) *Dub, khabbal*, (*Cynodon dactylon* Pers.) is the obvious choice for grassing down field drains and escape outlets, and its us for this purpose should be greatly extended. To get the best resuls it requires cultivation and where a quick cover is essential to stop further soil loss from newly made field drains, a top dressirg of chemical manure is justified; this is already the standard technique in American road-side drainage practice. It is most easily propagated by dibblirg in or rolling a supply of chopped roots cut with the *khurpa* (hand hoe), but must be protected from sheet wash until it has sprouted and taken hold, otherwise it will be washed away. It is often mixed with *Lespedeza* for American pasture sowings.

(d) *Khawi, ganni, gandhi*, (*Iseilema laxum* Hack.) the *musel* of southern U. P., a perennial bunch grass though sometimes creeping, which persists in heavier clay soils even with a very low rainfall, but in such conditions has a shorter season than

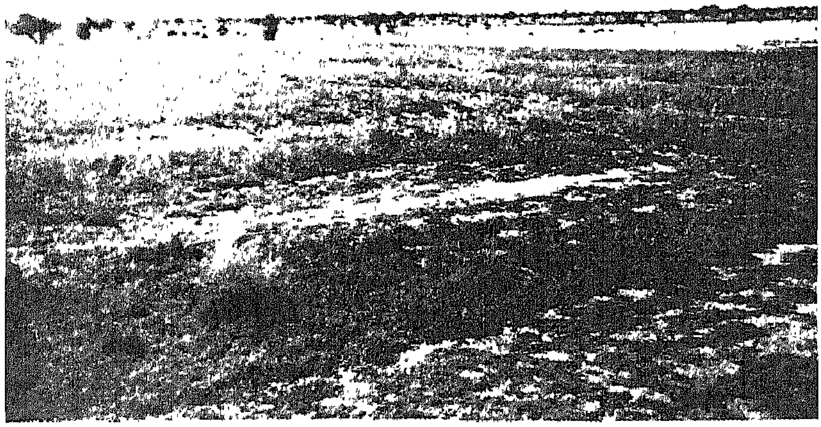


PLATE 5 (i).

Anjan Grass Sown in Hissar Livestock Farm on ground ploughed to 6" depth and ridged to form Kiar. Bundi.—Para 3.29.

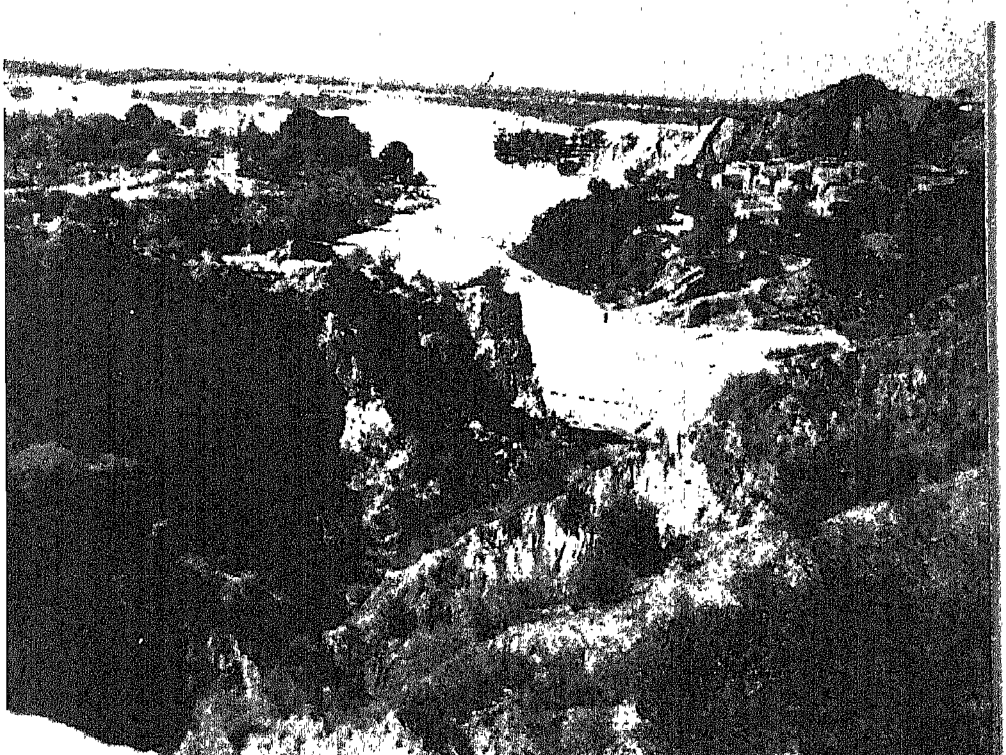


PLATE 5 (ii

Chohal Cho near Hoshiarpur Town showing the Siwalik outer fringe and progress of canalisation in the bro sandy waste on the alluvial plain below.—Para 10.12.

it normally shows under better conditions. As it is a matter of holding more moisture in the clay, contour cultivation will obviously help to improve its output and quality and extend its growing season.

(e) *Sariala* (*Heteropogon contortus* Beauv., spear grass) is the commonest hillside cover in the Punjab. Owing to its crop of barbs it can only be harvested either as a real hay before flowering, or after it is fully mature, when the bunches of barbs can be shaken out during or after cutting. It should not be sown along with other grasses but kept as a pure crop. Where it is firmly established as a natural crop it is not feasible to oust it or replace it with anything better, owing to its persistency. The Military Farms harvest it for hay after combing out the barbs from the standing crop with a machine, but this is only feasible on level and regularly bunded fields, not on a hillside. Contour trenching of typical *sariala* areas will result in the grass producing a much heavier yield and prolonging its growth season well into the winter.

(f) *Chimbar* (*Eleusine flagellifera* Nees., *ganthil* in Hissar) is the commonest grass of our irrigated forest plantations where it produces a rank growth of hay which is seldom harvested. In *barani* land its yield is much poorer and in Hissar and Sirsa it compares poorly with *anjan* both in yield and value of hay.

(g) *Baru* (*Sorghum halepense* Pers., Johnston grass) is bad grass in almost every way and should never be propagated deliberately, although if it comes in as a volunteer in drainage channels which are steep enough to be eroding, it can be made good use of as a green fodder. At very young stages it is however dangerous to stock, and again when mature is too coarse to use direct, but it has been successfully used by the Military Farms for silage by cutting it heavily when immature. It is exceedingly difficult to uproot once it is established.

(h) Dab (*Eragrostis cynosuroides* Beauv. or *Desmostachya bipinnata* Stapf.) is another inferior and troublesome grass prevalent on abandoned cultivation and on heavily grazed areas, and where it is common the only chance of improvement appears to lie in complete closure to grazing for a period during which the land is contour ridged, the *dab* eradicated, and better grasses cultivated after which rotational grazing should ensure that the better grasses are not again driven out by it.

(i) *Lamb, lampa* (*Aristida depressa* Retz) is typical of the poor soils of Kangra and Gujrat uplands which have been eroded down to a clay subsoil, and also often persists as the commonest grass under scrub and chil pine canopy under heavy grazing.

Owing to its seed being armed with short spikes its only value is as a green fodder, but it is so thin as to be not worth cutting, so the only way to utilise it is controlled grazing carefully regulated to what it will stand. If this is combined with contour mattocking and sowing of better grasses, the *lamb* is unlikely to persist, but in extensive forest areas which cannot be taken up for improvement, grazing is the only way it can be utilised.

(j) *Swank* (*Panicum colonum* Linn, syn. *Echinochloa colonum* Link.) is a coarse fleshy grass of the eastern districts, a nutritious fodder but does not make good hay and is best used green. It favours heavy soils and persists on the heavier soils even in dry areas such as Hissar.

(k) [*Kana sirkanda, munj, sarpat, sarut* (*Saccharum munja* Roxb.) has in the past been looked upon as a danger, but more recently its use in the reclamation of sandy cho beds has shown it to be invaluable. Its function for cho reclamation is described in Chapter X and as a wind-break in Chapter XII. Its commercial uses are many] e.g., for making roadways across sandy *cho* beds; *chiks, jaffri* and thatching; and in times of scarcity as fuel; but as fodder only the young leaves can be used. *Saccharum arundinaceum* Retz., the true *munj* grass, is generally restricted to the main river *belas*. Some of the sugarcane crosses from cane grass stock should be of value in our sandy *cho* reclamation.

(l) *Kahi, kans* (*Saccharum spontaneum* Linn.) is another pioneer whose use in sand reclamation has now been established, as it is almost invariably the first volunteer in any closure of torrent-ruined land. In fact its continued absence from a closure area shows pretty clearly that the closure is nominal and that grazing is being allowed to continue. Once established it requires only protection against excessive grazing to bind the surface and provide cut fodder, which can be used right through the summer and early rains, when other grasses are not fit for cutting, so that it is invaluable in the transition period before we can get a more permanent grassland management established.

(m) *Bhabbar* grass, *sabai* in U. P. (*Eulaliopsis binata* (Retz) C. E. Hubbard, syn. *Ischoemum angustifolium* Hack.) is not normally a fodder grass, but finds a ready market as the raw material for paper. The only mill in the Punjab using this material is the Shree Gopal Paper Mill at Jagadhri and its capacity is not likely to be exceeded even after many years of energic planting. The current price is Rs. 1|12|- to 2|4|- dry grass at railhead, and it thus fetches more than fodder grass except in times of fodder scarcity; when the fodder price competes with it much bhabbar grass finds its way into fodder consignments from Ambala and Hoshiarpur.

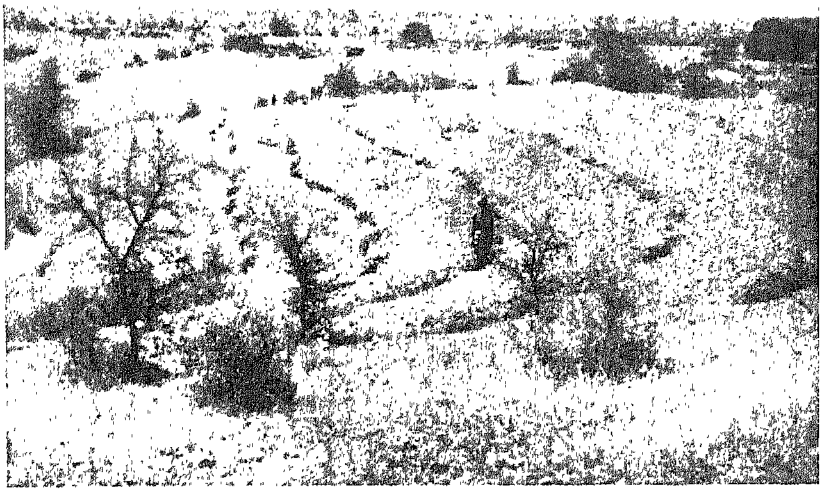


PLATE 30 (i)

The first stage in the reclamation of steep stony stopes is to stop further ploughing, then dig contour trenches and sow forest tree seed or plant with bhabbar. This area is ready for bhabbar planting. Bachoi Maili Working Plan Area.—Para 4.21 (m).

PLATE 30 (ii)

A few acres of contour ridging on waste land made by hand labour for demonstration to our own staff and for discussion with local zamindars. Following the contour strictly across land already eroded makes a very sinuous line, which the cultivator naturally dislikes as it complicates his ploughing between the ridges.—Para 3 39.

The natural distribution of this grass is on the rockier and drier parts of the foothills from Nepal westwards almost to the Indus, but in the Punjab it is most plentiful between the Jumna and the Ravi rivers. It has been planted so extensively in the Hoshiarpur Siwalik lower fringe that this division is now producing 6000 tons, the value of which amounts to about Rs. 2½ lakhs, all of which goes to villagers' and societies' revenue. Planting work is comparatively simple but much money has been wasted in careless planting, particularly in Kangra. As the grass roots are thin and easily torn from the stumpy "set" of leave bases, large clumps should be uprooted and divided with care and each separate "set" should be dipped in a bucket of thick mud and transplanted as quickly as possible. Long exposure of the root or careless thrusting of the set into poor soil without preparing a hole to accommodate the thin roots will inevitably lead to heavy losses.

4. 22. *Introduction of Foreign Plants for Pasture and Fodder*.—Although studies of drought-resistant plants have been in progress by the U. S. Bureau of Plant Industry for some 40 years, it is only in the last 15 years that extensive introductions have been attempted; the most widely successful species are the leguminous *Lespedeza* (see para, 12. 42) and the crested wheat-grass (*Agropyron cristatum*) which was developed in the dry farming belt of central and western Canada but has now been accepted for grassland improvement in many parts of U. S. A., and should be worth trial in the Punjab foothills.

Local types and strains have been produced by nature, and it is by breeding from these and from the pedigree strains of the plant breeding stations that hardy plants of real fodder value can be produced in quantity to meet our various needs of climate, soil and livestock. Unfortunately there is no grass seed trade established in India, so we are dependent upon our own efforts in collecting suitable seed.

4. 23. *Grazing Incidence*.—The principal forage plants are of the bunch-grass type which under favourable climatic conditions may cover 70% of the ground, but the same species persist far into the arid zone merely by reducing the percentage of ground covered to as low as 10%; root competition accounts for the wider spacing, each plant requiring more room to collect its quota of soil moisture. It is partly this very wide spacing in the arid zones which lowers the grazing capacity as one approaches desert conditions. The American figures for the acreage required per head of livestock under different conditions of rainfall are of

considerable value to us in India in helping us to realise how grossly our dry zone waste-lands are over-grazed, for within each rainfall belt the amount and quality of fodder produced is roughly the same in both countries:—

Average annual precipitation, inches.	Grazing capacity for land in good condition, acres per animal.
5-10	60-200
10-15	35-80
15-20	25-45
20-25	12-35
25-30	8-15
30 and over.	3-12.

(W. R. Chapline and C. K. Cooperider: Climate & Grazing in *U. S. Yearbook of Agriculture,* 1941).

For stopping erosion the value of well stocked grassland reclaimed by means of foreign introductions is brought out by an example quoted from the same publication. At Boise in Idaho, rains of 1¾ inches falling in half-an-hour were almost completely absorbed on slopes of 30 to 40% gradient covered with a 35% stand of introduced wheatgrass, whereas from a poorer cover of inferior local grasses on land which had been overgrazed 34% of the rain was lost in run-off, and from the same slope carrying weeds the loss was 64%. It is a pity we have to go abroad for such figures; similar measurements for Indian conditions would doubtless show even more striking differences. The possibility of establishing good foreign species decreases with the progressive increase in aridity of climate and difficulty in protecting any plants we may get established in the western districts.

4. 24. *Possible Introductions.*—Experiments at the Institute of Plant Industry at Indore have shown that the following grasses are useful for planting on bunds and field edges in Central India:—

(1) Guinea grass, (2) Napier grass, (3) Sudan grass, (4) Buffalo grass, (5) Rhodes grass, (6) Dallis grass, (7) Kikuyu grass, (8) Wimmera rye grass, (9) *Andropogon laniger* (common in Hissar *birs*), (10) Anjan (*Cenchrus ciliaris*), see para. 4. 21 (a).

Notes on some of these are given below:—

(1) Guinea grass (*Panicum maximum*) native of Africa is grown in India as far north as Lucknow but requires irrigation and is frost tender. It should however do well on bunds under trees and needs to be kept free of weeds.

(2) The use of Napier grass (*Pennisetum typhoideum*) in alternate rows between crops of gram or horse gram is recommended by Kanitkar, and in Bengal it is reported as making a good soil cover under *sal* plantations.

(3) Sudan grass (*Sorghum vulgare* var. *sudanense*) is used in U. S. A. along with millet as a hay crop, but it sprouts late and thus allows a lot of erosion before it "takes hold" of the soil. (A. F. Gustafson in *Conservation of the Soil*, 1937). It is however quite widely used in the arid Southern Plains to stop erosion in ploughed land by sowing in contour rows.

(4) Buffalo grass (*Buchloe dactyloides* syn. *Reana luxurians*) is the best turf grass of the Southern Plains of U. S. A. and is able to stand up to great extremes of drough and heat once it is well established. It is however a bad seeder so will be difficult to introduce. It does better on clays and loams than on loose sandy soil and stands heavy grazing. It is used in the same way as *Cynodon dactylon* for grassing down field drains and roadside drainage ways and is propagated in the same way (see para. 4.21 e). (Savage D. A. in *U. S. Dept. Ag. Circular No.* 328, 1935).

(5) Rhodes grass (*Chloris virgata*) has done well in Lahore Grass Farm on field bunds and thrives on light rainfall and long droughts on any land except stiff clay or waterlogged land. Sow 10 lbs. seed per acre at beginning of monsoon or transplants 18" apart. It spreads quickly by runner but the Grass Farms keep it in rows inter-cultivated. Should be worth trying for consolidating field watts.

(6) Dallis grass (*Paspalum dilatatum*) is reported from U. S. A. to be too slow in spreading to be of much use for erosion control and seed supply is poor, but as it does well on the calcareous Mississippi Black Belt it might be worth a trial in Kalachitta and on the highly erosive calcareous *darrar* ravines of Gujrat and Ambala.

(7) *Kikuyu* (*Pennisetum clandestinum*) succeeds well on Sikkim hillsides and in Delhi gardens and Lahore Grass Farm where given irrigation water, and may have a future as a fodder crop in reclaimed sandy torrent beds or behind earth bunds where a steady moisture is guaranted. It is an excellent fodder. It resembles *dub* in habit though coarser in appearance. Seed supply poor so depends upon dibbling of cuttings.

For notes on the leguminous *Lespedezas* and Kudzu vine *Pueraria thunbergiana*) see para. 12. 42.

4. 25. *Hay Baling.*—Various types of baling machine are on the market, and in addition there are obsolete and rather heavy

contrivances which can occasionally be had cheaply from Military Farms stock. Possibly the most efficient is the McCormick Deering press which is reported as capable of making 300 bales a day at a pre-war cost of -|1|6 per bale for fuel, wire, and labour. A screw-pressure machine is used by the Jagadhri Paper Mill agency at Hoshiarpur to handle the loose grass which is collected at railhead before forwarding it to the mill by rail.

4. 26. *Fodder Trees and Lopping Rotations.*—Much has been written in past *Indian Foresters* about the fodder value of Indian trees, but little has been achieved by forest officers to regulate lopping effectively. Roughly speaking, if a tree belongs to an individual he treats it with sufficient respect to keep it alive and productive; in the case of the hill oaks and the *sohanjhna* (*Moringa oleifera*) he will even do the lopping on a rotation of 2 or 3 years in order to preserve them on his own land. But when the same tree occurs on government or common land he is quite merciless and lops it to death. The elaborate rules for lopping only over a certain girth and upto 2|3rds of the height laid down by the early forest settlements such as Kangra have proved quite unworkable in face of economic pressure and of the systematic flaunting of the rules, often with the willing co-operation of a corrupt staff. Protection of government property is so difficult that it has been seriously proposed that the department gives up further attempts to grow *kikar* (*Acacia arabica*) on roadsides as it is impossible to protect it from lopping. Under these circumstances the best chance for the future therefore lies in persuading the villager to grow his own trees on his own land, and where he has no land, to incorporate the waste, no matter whose hands it may be in, and form it into an estate which can be placed under the charge of a society formed of the villagers themselves. This has been attempted in Kangra where many of the societies have carried out tree planting in land still open to grazing, by fencing each plant with a thorn ring. It yet remains to be seen whether such trees can persist when destruction of tree growth has become so universal throughout the district; also whether a communally owned tree will be afforded the same protection which is given to that of a private owner who can personally enforce the rights of ownership.

4. 27. To save the remaining oak and *Olea* forests from extermination, government will have to make some arbitrary decisions in cancelling the rights of lopping which have been admitted under the forest settlement, and possibly the simplest way legally is to apply section 4 of the Chos Act to the heavily lopped areas, irrespective of whether they are already reserved

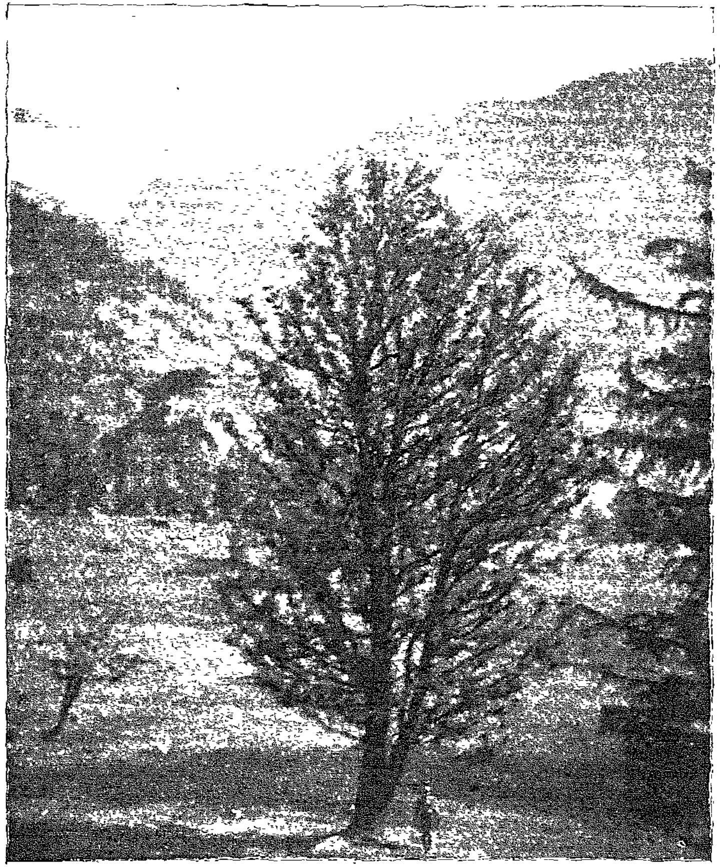


PLATE 6 (i)
Lopping rotation I—a recently lopped oak in Kulu showing careful [illegible]

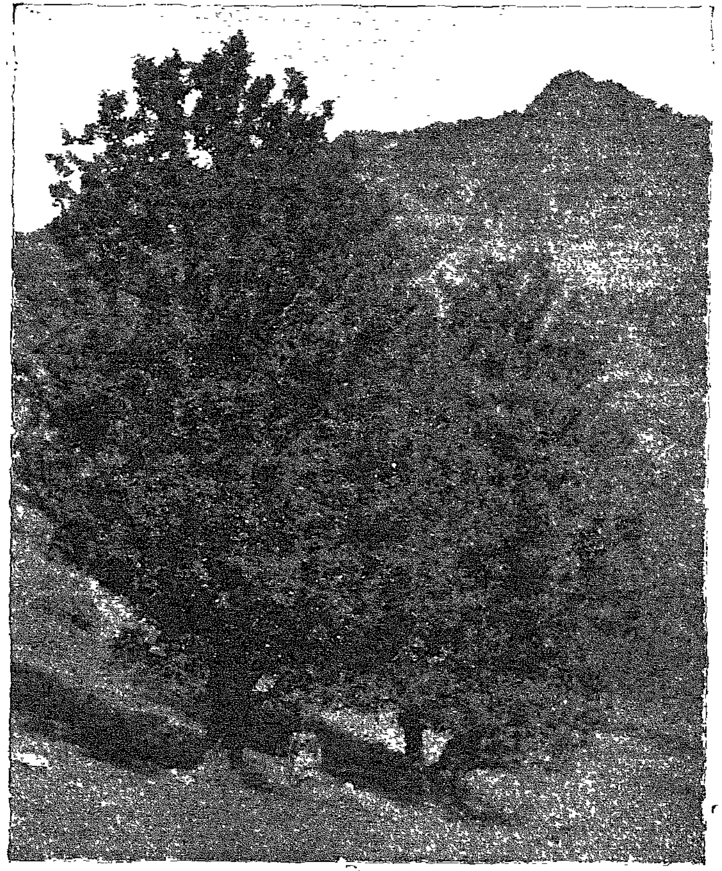


PLATE 6 (ii)
Lopping rotation II—a Kulu oak in its second year's growth since [illegible] of fresh foliage.—Para. 4.26.

forests, protected, demarcated, or village *shamilat;* the right-holders can then apply for compensation, though on the analogy of recent Hoshiarpur court decisions, it will be difficult for the owners to substantiate claims to loss when the very trees they claim are already dead or moribund as a result of excessive use of the lopping right. In Europe such misuse of rights would have been stopped legally long ago, as it is generally admitted and practised that a *right of user* can only continue so long as its operation does not prejudice the well being of the property. The definition of a *right of user* is that it must sustain itself, vide my *Land Management in the Punjab Foothills,* paras 5. 10 and 5. 11. The tragedy of all this unnecessary destruction which is leading indirectly to so much serious erosion, is that it could have been brought under strict control at any time within the last 80 years if government had not held throughout to a policy of appeasement to the forces of destruction. In many places such as the Dhauladhar of Kangra, and the Murree Hills and the Hazara Gallies, it is now almost too late, and desiccation has gone too far to be retrieved. All the more reason, then, for a more forceful policy from now on, to save what is left of the Punjab's forest estate, and build up fresh centres of supply of tree fodder to supplement the regular fodder and grass crops, by planting fodder trees and enforcing a suitable rotation. See plate 6.

The eastern districts are far better off in their choice of fodder tree species than is the west. The original oak and olive are all difficult trees to rear from seed or by transplanting, so we must depend largely upon substitute species. A list is appended to indicate the limitations of choice for the different regions of the Punjab.

4. 28. *List of Fodder Trees by Regions* (for cattle only, not horses).

Species.		Siwaliks.	S. E. Punjab	S. W. Punjab	Western Uplands.
Acacia arabica ... leaves & pods.	—kikar ...	I	I	I	I
Acacia modesta ...	—phulai ...	...	I	I	I
Acacia catechu ...	—khair ...	I	I	...	...
Albizzia lebbek ...	—siris ...	...	I	I	I
Bauhinia purpurea	—khairwal ...	I	...	...	I
,, variegata	—kachnar ...	I	...	...	I

Species.		Siwaliks.	S. E. Punjab	S. W. Punjab	Western Uplands.
Bauhinia vahlii ...	—malihan creeper	1	...	...	...
Butea frondosa ...	—dhak ...	1	1	1	1
Bombax malabaricum	—simal ...	1	...	...	...
Cassia fistula ...	—amaltas ...	1	...	..	...
Celtis australis ...	—batkar or ... khirk.	1	1	1	1
Eugenia jambolana	—jaman ...	1	1	1	1
Grewia oppositifolia	—biul ...	1	1	...	...
Garuga pinnata ...	—kharpat ...	1	...	...	...
Melia azedarach	—bakain ...	1	1	1	1
Moringa oleifera	—soharjna ...	1	1	...	...
Morus alba	—tut ...	1	1	1	1
Terminalia spp.	— ...	1	...	...	...
Olea cuspidata	—kao ...	...	...	1	1
Populus euphratica	—bhan ...	...	...	1	1
Zizyphus jujuba	—ber ...	1	1	1	1
,, nummularia	—malla ...	...	1	1	1

4. 29. *The Assessment of Grazing Capacity.*—For the preparation of village or society working plans it is essential to know how many animals can be supported in health on the grazing available so that a target for reduction of livestock can be fixed for given periods under the plan.

Mapping on a 4″ to the mile scale, a ¼ inch block represents 2½ acres, so mapping of the available grazing can be undertaken down to that intensity with a series of symbols which will describe the slope, soil, plant cover, intensity of erosion, present land use, proposed land use. Worked out in detail, this will eventually give a complete picture of the village's grassland resource which will enable the Working Plan Officer to fix arbitrarily the number of head of stock to be kept, the best rotation plan, the possibility of establishing hay reserves, and cultivation of fodder. In this assessment the contribution which tree fodders are to make will naturally find a place, but it must be realised that misuse of fodder trees will react more quickly than misuse of grassland. An entire forest of mature oak can

be exterminated in a few years by too heavy lopping, as has actually taken place in many village lands and also in demarcated forests in Kangra valley, and such a resource once destroyed will take many years of planting and protection to build up again. For this reason care must be exercised in including the available tree fodder in your calculation, for if protection is not fully enforced the position may be worse at the end of your working plan period than at the beginning. On the other hand the value of tree fodder has not been fully understood nor appreciated, and if skilfully incorporated in a seasonal feeding plan would add enormously to the effectiveness of stall feeding. As a small example, *kikar* pods if collected in April before their seeds have hardened provide an extra and valuable ration for milk animals just at a time when ordinary fodder and grazing is getting scarce. For the nutritive value of mesquite pods see also *Pb. For. Notes No.* 5; pods have 8% digestible protein and 45 starch equivalent compared with local hay's 0.5% and 30. The use of such material however is fortuitous and can hardly be depended upon when calculating a whole year's ration.

Details of the American methods of assessment of grass-land capacity have been given in my *Use and Misuse of Land; Oxford Forestry Memoir No.* 19, so need not be repeated here.

4. 30. *Natural Revegetation of Eroded Slopes and Land-slips.*—As in the case of plough-land so also with other bare slopes, whatever plant life becomes established helps to reduce erosion in two ways:—(1) temporary retardation of run-off merely by physical obstruction, and (2) the much more important and permanent effect of adding humus to the raw soil and thus making it more absorbtive. The rate of percolation is directly influenced by the structure of the soil, and it is this that we have to build up in our efforts to reclothe bare slopes. Nature will probably do this if left to herself, but by studying the ecological succession of the pioneer plant associations which come in naturally on all such slopes we should eventually be able to short-circuit some of these stages.

There are no Indian publications dealing fully with this subject of pioneer plant succession, but a list of pioneer plants on slips in Bashahr is given in my "Sutlej Deodar" (*Ind. For. Rec. XVII-IV*, 1935), also *Punjab Forestry Notes No.* 10 contains Mr. I. D. Mahendru's observations on succession in Kangra grasses.

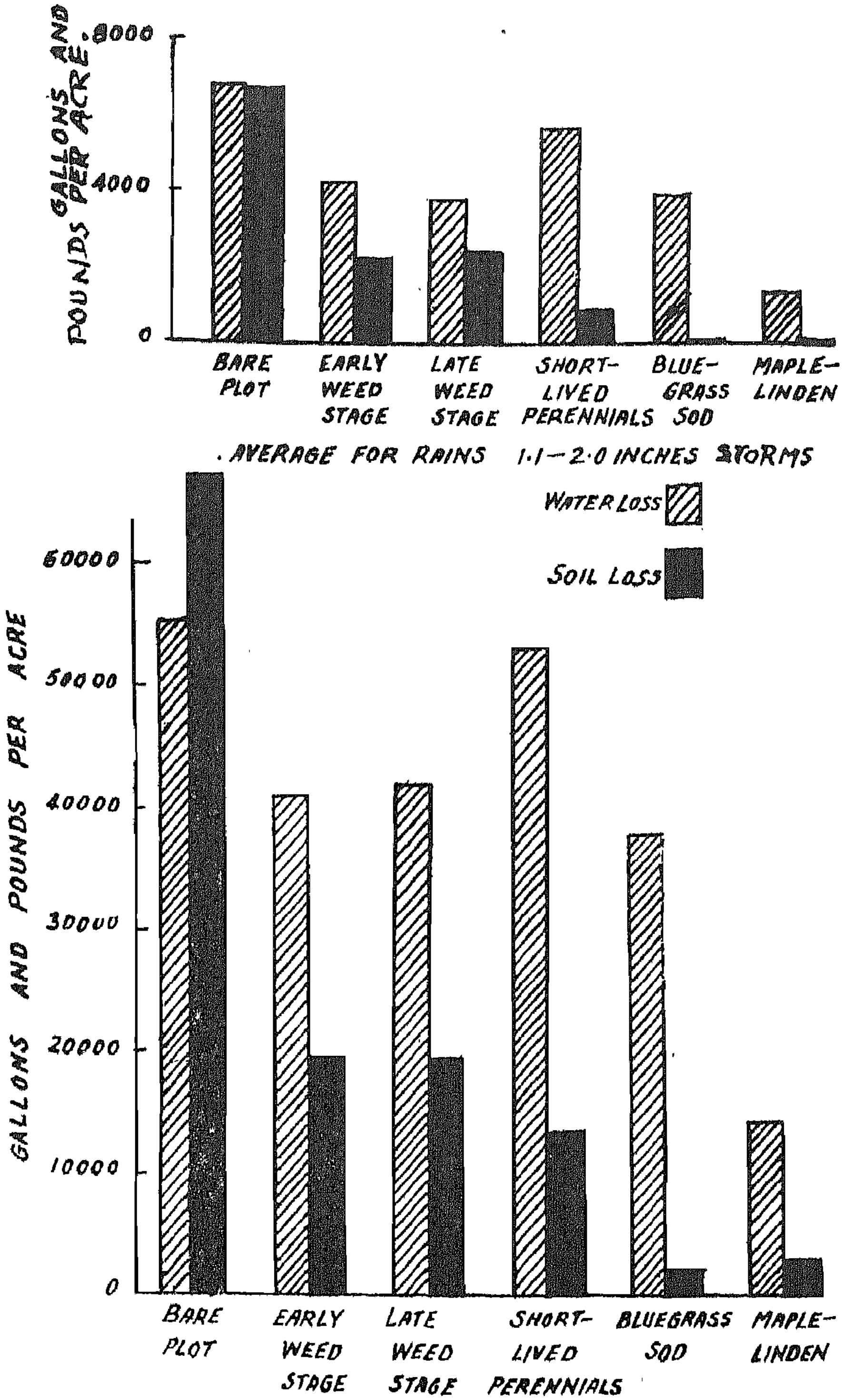


FIGURE 16.

Total water loss in gallons per acre and soil loss in pounds per acre calculated on the basis of per cent. slope for the stages of secondary plant succession. June to September 1936.

(*R. M. Warner and J. M. Aikman, Iowa State Journal of Science*).

The progressive improvement in slowing run-off and stopping soil losses by the various stages of reclothing a 40% slope of sandy loam overlying a calcareous subsoil at Ames, Iowa, is shown in Figure 16. The six stages start with bare soil and progress through the common ecological sequences of early weeds, late weeds, short lived perennials, grass sod and finish with a broadleaf mixture of maple and linden. (R. M. Warner and J. M. Aikman: The Relation of Secondary Plant Succession to Soil and Water Conservation, *Iowa State College Journal of Science*, Jan. 1943).

Chapter V.

WATER CONSERVATION IN NATURE; BUILDING UP SOIL FERTILITY

5. 1. Soil conservation is largely water conservation. The control of erosion lies in the handling of water. In dealing with water the law gives the public administration a much freer hand than in dealing with the land itself, even when that land is the property of the community and not of the individual owner. Public interests and rights in water correctly take precedence over private rights in it. Every catchment area from top to bottom forms a geographical unit, and whether the resultant stream be permanent or seasonal, our aim must be to make that stream serve mankind in the best way possible, whether for local use in fields and houses, or the wider interests of irrigation, electric power or other industrial projects. Each torrent must be tamed so that it contributes to local prosperity and resources instead of being an engine of destruction.

5. 2. The conservation of water falls roughly into two classes, namely (a) surface supplies from running streams and storage reservoirs, and (b) underground storage which can be released for us either by crop roots, or the dry weather flow of springs, or by pumping from wells. In terms of method, it can be divided into:—

(i) impounding water as it falls in each field by means of contour ridging and suitable methods of keeping the soil in a porous condition.

(ii) impounding run-off in water-stock ponds, reservoirs etc.

(iii) the spreading of flood water over land which will soak it up and thus replenish the underground water-table.

(iv) controlling the amount of water discharged into the atmosphere by manipulating the plant cover, whose water use by crops, weeds, grassland or forest, may be of major importance.

5. 3. In countries such as the Punjab which have been richly blessed with canal facilities fed by running rivers, the importance of (b) above has to a great extent been overlooked in the past, though the dangers of water-logging from over-zealous irri-

gation, and the advocacy of the wider use of tube wells to supplement ordinary well supply, have both combined recently to concentrate attention upon the problem of water use from underground storage. The proposals for a series of high dams have on the one hand attracted attention to the loss of water through evaporation from an exposed water surface; the amount of loss must obviously increase greatly with increasing aridity and continued high temperatures when the sites for dams are located in the arid or desert belts. On the other hand, the underground resources can easily be overworked, as has been found in Jullundur Doab, where the water-table has fallen to depths which are no longer economic for well irrigation. Underground sources are not subject to evaporation, but they are replenished slowly according to the rate of sidewise movement in the water-table, and of infiltration of rain. All these apparently disconnected facts point to the need for a better understanding of the usage and conservation of all available sources of water.

Rain and snow when reaching the earth are dealt with in several ways:—

(i) by interception by the plant cover before reaching ground level—i.e., direct physical protection.

(ii) by evaporation from the ground surface or from pond surfaces.

(iii) by transpiration of plants back into the atmosphere.

(iv) by percolation through the soil to build up the water table.

(v) by surface run-off into the nearest stream. (already dealt with in Chapter I).

5. 4. *Interception* by a forest canopy is known to be fairly high for light showers and for snow, but even when the canopy is a fairly heavy one, intense rainfall such as our monsoon storms is not interfered with to a very large extent, and in the case of our open scrub forests and plains *rakhs* the tree growth covers such a small part of the total surface that interference is not important, but with the decrease in tree cover the role of grass cover between and beneath the trees becomes of major importance. European data for spruce woods showed losses by interception of 63% for light showers and 39% for heavy ones; more recent American data give values of from 13 to 37% for different types of forest, the lower values being where the forest was open and the undergrowth sparse. No figures are available for a purely grass cover, but it can be presumed to be somewhere in the

neighbourhood of 5 to 10% except in the case of dense stands of *kana* grass such as is found in river *belas,* where it must obviously be more.

On the other hand, plant cover may actually seize moisture from the atmosphere. J. F. V. Phillips in South Africa showed that certain types of vegetation intercept and congeal appreciable quantities of surging mist which would otherwise never be deposited on the ground. Similarly in our arid Tibetan zone in the high hills, the deodar catches and congeals appreciable quantities of dew.

Even quite small amounts of low-growing vegetation appear to be very effective in protecting the soil from the direct attack of rain, provided the plant pattern is sufficient to cover the ground.

The soil saving effect of roots alone is of course less than when the whole forest plant is growing, and measurements by Kraemer & Weaver show that the protective value of trees and bushes is *more in their direct interference with the rain than in* the capacity of their roots to bind the soil (*Univ. of Nebraska Conservation Service Dept. Bulletin,* 1936).

This serves to show that it is a fallacy to imagine that because tree roots still exist in the soil, there will be no erosion. Even where grazing is excluded, broken ground will continue to crumble and slump between the trees. In our ravined lands partially uprooted trees are frequently seen whose roots have been exposed by erosion to such an extent that the tree falls over or dies.

There is however another side to the picture, and that is in the value of any residue of grass or jungle growth which may be left in soil when agricultural crops have been introduced, or where the farmer has had the sense to introduce grass into his rotation of crops. Experimental plots at Zanesville, Ohio, showed that following a heavy grass crop which was ploughed in before taking three successive crops of maize, soil losses were only 31 tons per acre the first year, but mounted to 106 tons the second year and 132 tons in the third, showing that resistance to erosion lay in the ploughed-in grass roots. As they decayed, soil losses increased. This figure for the third year corresponds closely with the Sholapur measurements of loss from a *jowar* field on a 1 in 80 slope in Bombay.

It is experience of this kind which has led to the recent enthusiasm in America for the preservation of all plant residues without even ploughing them in, but planting the new crop between the rows of stubble and trash left from the previous one.

As this forms a rather revolutionary departure from the orthodox Indian farming methods, a detailed discussion of its possibilities is given later (para. 5. 27).

5. 5. *Evaporation* from a soil surface covered with vegetation cannot readily be separated from transpiration losses, but must obviously be less than from bare ground. In the case of bare ground the old theory of capillary attraction drawing water up from considerable depths has now been disproved. Dr. B. A. Keen's work in this line is of the greatest importance to the Punjab and deserves to be better known. Roughly he has proved that a bare moist soil subjected to drying by sun and wind will dry out only to a depth of not more than 8 inches, and that the rest of the moisture held by the soil below this tends to stay where it is, and is not drawn upwards to any appreciable extent. This aspect of water conservation will be dealt with more fully under Chapter XII, Wind Erosion and Dry Farming Practice. South African workers estimate that from showers of ½" or less falling on bare soil, the whole of the fall is returned to the atmosphere and none finds it way to the water-table.

5. 6. Evaporation of moisture is a very potent and important factor in soil conservation (a) through losses of moisture from soil, thus injurious to afforestation work and field crops, (b) through losses of stored water in reservoirs and tanks. N. V. Kanitkar in *Dry Farming in India* (which should be in the hands of everyone connected with soil conservation work) quotes many actual measurements, pointing out that loss takes place not only in the hot and dry months but also in the breaks in the monsoon, which in our dry areas may give 4 days of evaporation for every one of rainfall or high humidity. At Sholapur, Bombay, for a periodic rainfall of 24" in 6 months the evaporation amounted to 17" while for the drier area of Bijapur the figures were 13" fall and 11 to 11⅗" loss. Experiments on the bare fallow of fields gave similar figures with percentage losses ranging from 68—75% for the Bombay stations, but up to cent per cent loss for Rohtak, where in 7 months 8.31" rainfall was more than accounted for by 8.46" evaporated.

In the natural grass-lands of the arid Great Plains of U. S. A. evaporation from a free water surface is reckoned to be 34 to 38 inches depth of water in the north, increasing to 48 to 55 inches in the southern and hotter part. Evaporation has a serious effect in dispersing the effect of light showers of rain, and although grass-land persists in Montana with 14 inches of rainfall, it takes 21 inches of rain to produce similar grass-land in the hotter Texas.

In the Tonto National Forest in one of the hottest and driest parts of Arizona, experiments showed that the natural grassland plants will absorb and transpire as much water as is lost from a free water surface, provided they are fed this water. But such plants do not under ordinary conditions touch this amount of water, and in fact they transpire little more than is evaporated from bare soil of a texture comparable to that in which they are growing. (Chapline, W. R. and Cooperrider, C. K. in 1941 *U. S. A. Yearbook of Agriculture*).

Evaporation from a free water surface has been variously estimated for tropical and semi-tropical conditions as being in the neighbourhood of 6 feet depth of water lost each year, but this loss is not regular or continuous, being at a maximum when the temperature is high and the humidity of the air is low. This figure bears no direct relationship to losses from either bare ground or plant covered ground, but the magnitude of the figures is an indication of the need to study all the means by which we can store water underground rather than have it in ponds or tanks. Evaporation from free water surfaces such as reservoirs reaches very high figures. For Pericha Reservoir, Jhansi, the annual loss was measured as representing 110½" depth of water or 5893 acre feet per square mile. Data for the Punjab arid zone will probably range even higher, so that this factor must be allowed for in every attempt to store water through the hot weather, whether for livestock, power or human consumption.

5. 7. *Transpiration* is the process by which all plants draw moisture from the ground, use it for their own growth, and transmit the excess back into the air through their leaves. The measurement of this water loss is an exceedingly difficult and complex piece of research, and results to date indicate that the figures obtained fluctuate wildly for the same plant species according to whether it can tap a good supply of water or not, the extreme case being the ease with which eucalyptus can drain swamps by their powers of excessive transpiration, whereas under arid scrub jungle conditions the same species can persist with very low water use. A figure frequently quoted is that the average plant requires 1000 lbs. of water to produce 1 lb. of dry plant tissue. American figures of plant consumption of water are in inches of rain per annum:—short grass 10" to 20"; tall grass 20" to 30"; pines 20" to 40"; hardwoods slightly higher than conifers. On the South African veldt with a thin tree scrub and bunch grass cover somewhat similar to our Attock rakhs, no water percolated below 4 ft. depth during three years, the rainfall being all used by the vegetation, even though 25" fell in one period

of 6 months (F. Grundy in *East African Agric. Journal* for January 1946). Other figures for South African conditions are:—grassland 22″ of rain used in a four months season; deciduous thicket, 38″; riverine forest 90″; out of these three types, the grass is the only one which leaves a margin of moisture which is spared to build up the water-table by allowing part of the rain to percolate to the deeper ground. (Staples R. R. in *Annual Reports for Tanganyika Territory Animal Husbandry Dept.*, 1933 onwards). This is an important feature of grass-land as compared with tree growth which should be verified for Punjab plains conditions. It also points to the need for the farmer selecting those crops which make the least demand on soil moisture where the supply is critical, as it is in most of our *barani* areas and throughout the unirrigated desert fringe.

5. 8. Every soil conservation worker must have a clear knowledge of the *water usage of plants* and should be constantly applying this knowledge to his own local problems. The following details and definitions must therefore be fully mastered:—

The *field moisture capacity* of a soil is the amount of water, expressed as a percentage of the oven-dry weight of the soil, which is held in a soil against the forces of gravity after excess moisture has removed itself by downward drainage of the gravitational surplus. A typical Punjab alluvial soil may have 18% moisture at the close of the monsoon period, this means that in the first 5 ft. depth, 11 inches of water have been held.

The *wilting point* is the amount of moisture present in a soil when plants growing in it can no longer remain turgid, but wilt and die, this likewise is expressed as a percentage of the oven-dry weight of soil. (At this point the soil need not be really dry either to the feel or as expressed in this percentage, for a considerable amount of moisture may be held in the soil crumbs and yet cannot be absorbed by the roots.

The *water-table* is that point within the ground beyond which the soil or rock is saturated, thus constituting an underground reservoir, though not of freely moving water.

5. 9. After rain, water moves downward through and between the crumbs of soil. The soil retains whatever amount of moisture it can upto its own peculiar *field moisture capacity*. The rest finds its way gradually down to join the reservoir below the water-table level, the process usually taking several days. When any further quantity of rain comes and is absorbed by the surface, an equal quantity of water will be automatically released from below to join the water reservoir. The field moisture capacity is the practical upper limit of soil moisture under con-

ditions of unobstructed drainage. When all gravitational surplus has drained through, further downward movement practically ceases. Figures of field moisture capacity for typical Indian soils vary between 10% and 43%. The particular figures for our various Punjab soils would be most valuable to know, but unfortunately it requires laboratory apparatus and a skilled soil analyst to assess the data. We can however get data for special areas measured through the courtesy of the Agricultural Chemist, Lyallpur.

5. 10. The depth to which the soil must be wetted before the surface layer will have attained a moisture content as high as its field moisture capacity varies from 12 to 30 inches for ordinary soils, and for deep soils comparable with the Punjab plains alluvium may be as much as 36 to 42 inches. (E. A. Colman: The Dependence of Field Capacity upon the Depth of Wetting of Field Soils. *Soil Science,* July, 1944). This suggests that shallow hand-watering may help a plant temporarily, but only deep irrigation or careful moisture conservation practices are likely to build up drought resistance in a young plant by encouraging deep rooting. This is borne out by experience in the Punjab irrigated forest plantations.

If moisture in the upper layer of top-soil exceeds the field capacity of the whole, then water will move down gravitationally, but if the soil lower down is water-logged no movement is possible. If on the other hand the whole has dried to less than field capacity, the excess water newly acquired by the surface layer will be held there until the whole profile gradually resumes field capacity; thus no percolation will take place until the whole has reached field capacity. This rough rule is however greatly modified by the presence of deep-rooted plants, for old roots die and leave virtual direct channels for the rapid percolation of water down to the water-table.

5. 11. Wilting begins at a stage when absorption of water by the roots is so slow that it cannot catch up with the plant's transpiration losses. The rate of absorption gradually slows down as the *available* water decreases, the available water being what is held in a given soil between the two limits of field moisture capacity and wilting point percentage. When the whole soil profile is at full field capacity, all roots can function freely in drawing moisture, but as the available moisture decreases and drops to nearer the wilting point by the action of the plants themselves, so the task of the roots becomes increasingly difficult. The amount of water used up by the plants plus what is lost by evaporation from the soil surface is the same quantity as is necessary

to restore the field moisture capacity, and it is not until after this has been supplied that any further addition can be made to the water-table.

Clay holds a much larger quantity of available moisture than sand, therefore sandy soils are to be preferred for the purpose of contributing to underground supplies. The difference is clearly indicated in the following table quoted from F. J. Veihmeyer, *Trans, Amer, Geophys. Union*, 1938.

	Fine sand	Sandy loam.	Silt loam.	Loam.	Clay.
Moisture equivalent %	3.2	9.5	16.1	21.7	28.4
Wilting point %	1.0	2.9	7.5	10.3	13.4
Available moisture %	2.2	6.6	8.6	11.4	15.0

5. 12. Combined losses by evaporation and transpiration from whole catchment areas are assessed in several classic investigations such as Hoyt and Troxall's (*Amer. Soc. Civil Eng.*, 1932), Nicholson's in Kenya (J. W. Nicholson-*For. Dept. Pamphlet, No.* 2, Govt. Printer, Entebbe, Uganda, 1930), and Benskin's in Chota Nagpur (E. Benskin.—*Ind. For.*, October & December 1930), Hirata's in Japan (T. Hirata.—*Contributions to the Problem of the Relation between Forests and Water in Japan*: 1929), and the well-known Wagonwheel Gap investigation by Bates and Henry in Colorado (C. G. Bates and A. J. Henry.—*Monthly Weather Rept. U. S. Dept. Agric. Supp.* 30, 1928). All go to prove that one cannot afford to be dogmatic about the effect of a forest canopy as opposed to a lower canopy of grass and herbs in reducing evaporation. In the American and Japanese experiments the effect of "denudation" of forest areas was carefully measured and it was found that the difference in comparative run-off reflected fairly accurately the state of the canopy. These were all mountain areas with a well-distributed rain and snowfall where a rapid regrowth of aspen or other shrubs *unaffected by grazing* reclothed the whole of the denuded area within three years,—a very different interpretation of the word "denudation" than would be given by any Indian forester, who would naturally envisage the complete destruction by fire and over-grazing of any regrowth which comes up to replace the felled trees. Even under favourable circumstances, the erosion ratio in the Wagonwheel Gap experiment increased from 0.822 to 7.002 i.e. $8\frac{1}{2}$ times as high, during this very temporary denudation. In face of such figures the question of how much comparative evaporation goes on from forest or grass land canopy does not appear to be of very

great importance, particularly as the factors such as underground drainage and artesian water action make it well nigh impossible to get absolutely reliable data.

5. 13. *Evidence of Rainfall and Stream-flow Changes in the Punjab.*—There exists a popular belief that changes in rainfall have shown a definite trend. In the case of the eastern districts of Hoshiarpur, Jullundur and Ambala the belief is that the rainfall is less in total and more erratic in its distribution now than it was 50 or 70 years ago. In the case of the irrigation colonies the belief is that irrigation has itself attracted rain and that the total fall is now greater than it was. A recent paper by Prof. J. B. Seth (Rainfall in the Punjab, *Ind. Sc. Congr* 1939) shows that from the available evidence nothing can be proved either way. This is confirmed by the more general meteorological concept of rainfall being of two main types:—(a) monsoon, due to clearly defined and powerful seasonal currents which are unlikely to be influenced by the presence or absence of vegetation, and (b) "instability rainfall" which is produced by sudden local changes in cloud conditions and which can be influenced to some extent by vegetation acting as a dispersing agent which serves to eliminate differences in the electric potential of the cloud layers. As most of our Punjab rainfall is of the monsoon type the vegetation is unlikely to have any appreciable effect on the *actual total rainfall*. Its effect upon the utilisation of this rainfall is however a different matter, as has already been clearly shown in Chapter I. The effect of vegetation upon the available moisture in catchments is in fact the scientific basis on which our whole soil conservation programme is framed.

The conviction appears to be held now by a majority of competent engineers that the decrease of dry weather flow is becoming a more recognisable phenomenon than the increase in intensity of floods. Both phenomena are accepted as established though only in a very few cases do river readings go back far enough to provide accurate data which can prove these as facts. The behaviour of the water-table in Hoshiarpur plains below the Siwalik has followed closely upon the history of the Siwalik itself with a steady drop following a prolonged period of destruction of hill forest, to be replaced with an upward trend which is now becoming obvious and follows upon a regime of afforestation and conservation on the foothills, particularly in the areas of our working plans where afforestation and gully plugging work has been concentrated.

Similarly the forest belt in the Panjal and Lohara *thapas* of the Sohan valley has maintained its spring-flow, although the

hills both above and below this belt have become *desiccated*, presumably as a result of disforestation.

These trends fit in so well with what we know of denudation and misuse of land in the catchments that it is impossible to avoid the conclusion that the balance of seepage|run-off is inevitably deteriorating. It has already been stressed that deterioration of run-off conditions is due to destruction of plant cover, and the cause of this destruction have been analysed under plough land and waste land.

5. 14. *Physical Function of Forest.*—The effects of forest upon the available drainage of catchments can be summarised into:—

(a) influences temperature of air, reducing extremes of both heat and cold.

(b) influences temperature of soil, again reducing extremes of heat and cold.

(c) increases the relative humidity of the air through transpiration,

forest (Sperbelgraben) run off 50%, combined transpiration & evaporisation 50%.

pasture (Rappengraben) runoff 62%, combined transpiration & exaporation 38%, (See para. 5. 17 and H. Burger's report).

(d) gives physical protection to soil against erosion.

(e) increases rainfall of the "instability", non-monsoon, type, and thus tends to shorten drought periods.

(f) maintains forest floor nearer to *field moisture capacity*, and therefore maintains a steadier rate of percolation than in the case of bare ground.

Measurements in America by C. L. Forsling (*Tech. Bull. No.* 220, U. S. Forest Service, March 1931), and W. A. Rockie and P. C. McGrew (*Bull.* 271, *State Coll., Washington,* July 1932), and in Burma by F. H. Warth.—(*Source and Value of Silt in Burma,* Rangoon, 1911), have confirmed the classic Swiss experiments of the Emmenthal and many other older observations of the destruction which follows in the wake of erosion. As long as the natural soil profile is protected by the vegetation which best suits the locality, it continues to yield a regular run-off, but whenever this cover is interfered with by heavy grazing, fire, or erosion, —or as so often happens in India, a disastrous combination of all three,—the soil profile is radically altered and striking differences in the run-off are bound to occur.

Forsling's experiments in Utah do not set out to compare forest with non-forest covers but they show clearly that the increase in the density of the vegetation from 16 to 40 per cent. of a complete cover, and the replacement of certain plants by others with more extensive and more fibrous root-systems, reduced the rainfall surface run-off 64 per cent. and rainfall erosion 54 per cent. W. C. Lowdermilk's experiments (*Jour. Amer. Agric. Engineers*, April, 1931, and *Proceedings Intern. Congr. Forestry Experimental Stations*, Stockholm, 1929) in California show that the surficial run-off from burnt and bare surfaces exceeds that from litter-covered surfaces by 3 to 30 fold, and erosion by 50 to 6000 fold, and that forest litter continues to function in this respect far beyond its complete saturation with water under an artificial monsoon of 80 inches of rainfall in 23 days. Both of these results emphasize the importance of any good vegetational cover in reducing floods and controlling erosion and the need for the strictest regulation of grazing, which so rapidly destroys this cover on slopes subject to torrential rainfall.

The position has been ably summarised by Raphael Zon in his *Forests and Water in the Light of Scientific Investigation.* (U. S. Printing Office, Washington, 20 cents. 1927) which is generally recognised as the most authoritative of the many publications on this subject:—

"In level country, where there is no surface run-off, forests, in common with other vegetation, act as drainers of the soil; hence their importance in draining marsh and improving hygienic conditions. In such country their effect upon springs is unimportant."

"In hilly and mountainous country forests are conservers of water for stream flow. Even on the steepest slopes they create conditions with regard to surface run-off such as obtain in a level country. Irrespective of species, they save a greater amount of precipitation for stream-flow than does any other vegetable cover similarly situated. They increase underground storage of water to a larger extent than do any other vegetable covers on bare surfaces. The steeper the slope the less permeable the soil, and the heavier the precipitation the greater is this effect."

"In the mountains, the forests, by breaking the violence of rain, retarding the melting of snow, increasing the absorptive capacity of the soil cover, increase underground seepage, and so tend to maintain a steady flow of water in streams."

In view of the widespread destruction of Northern Indian forests, and particularly of the *Quercus* forests of the Dhauladhar of Kangra, the Simla hill states and the Murree & Abbottabad

Gallies, all of which lie in the heaviest monsoon altitudinal belt of 4000 to 9000 feet, there is every reason to anticipate a series of major calamities in the way of flood damage which must inevitably follow upon the wholesale destruction of Nature's own safeguards.

5. 15. *Run-off and Erosion from Snow-fall and Snow-fields.*—The contribution which snow makes to stream-flow in the Punjab rivers is of tremendous importance in both irrigation and hydro-electric supply, but has not been sufficiently studied. The only data of depth of snow-fields registered by the Meteorological Department are those derived from forest subordinates' reports on the depth as measured at certain passes and fixed points in the high hills, and this is by no means reliable. Some years ago the Irrigation Research Institute purchased a Mount Rose snow sampler outfit from America but so far this has not been made use of in any way, though its regular use would have added considerably to our knowledge of past seasons' snow melt and hence to the accuracy of estimates of probable stream-flow during the following irrigation season. The conventional factor of 1 foot of snow being equivalent to 1 inch of rain may be wildly inaccurate.

The actual average depth of snow accumulated in the Western Himalaya at the end of each winter is about 10 feet at 10,000 feet, and certainly not more than 16 ft. at 14,000 feet, above which precipitation apparently does not increase perceptibly with further increase in height. With a water equivalent of 30% this gives us 36" at 10,000 ft. and 60" at 14,000 ft. Very little of this high level snow finds its way into the river until the height of the summer, and the graphs of streamflow for all our main rivers show a fairly steady rise throughout late April, May and June, often telescoping into the first onslaught of the monsoon rains, which fall most heavily in the altitude belt of 4000 to 9000 feet in the foothills. It is the occasional conjunction of the two, snow-melt and monsoon storm, which produces phenomenal floods in the plains.

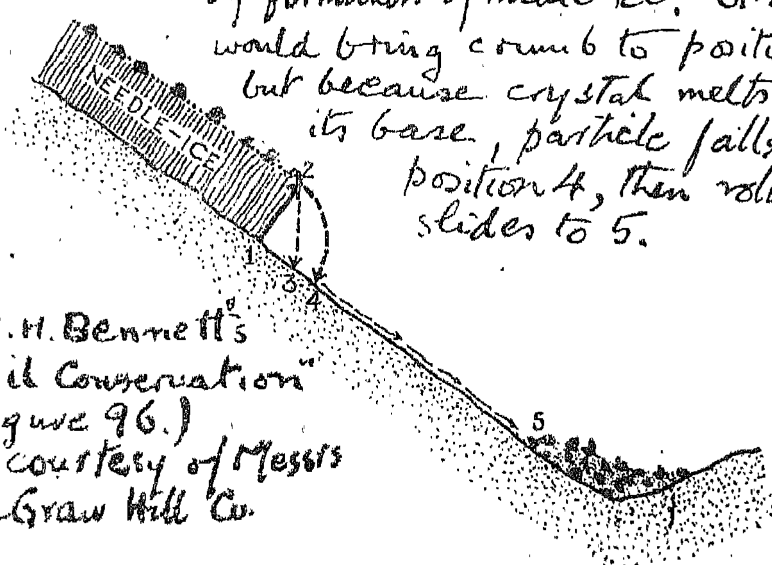
5. 16.—*Erosion from Melting Snow and Frost.*—The fate of the snow which is deposited in the lower range of snowfall is less predictable, for much depends upon the condition of the soil before it falls, the condition of the snow when it falls, and the subsequent weather. If the ground is frozen to start with in the below 9000 ft. belt, much of the snow when it does melt will form surface run-off without penetrating the ground, whereas if the snow itself is soggy when it falls and the ground has been thoroughly wetted previously, the snow immediately contributes directly and largely to maintaining the ground in a water-logged

condition. Bright clear days subsequent to snowfall will preserve it at low levels even with fairly high temperatures, whereas dull cloudy weather will precipitate a thaw. Avalanches of wet snow are a common feature of waste land and poorly terraced cultivation but seldom occur in fully protected forest at these low levels.

As affecting river supplies the amount of serious erosion and gullying which takes place along this lower fringe of the snow belt is not yet fully appreciated. Banks of wet snow lying on a slope of poorly terraced cultivated land have been seen to cause deep gullies in the potato fields of the Uhl valley in exactly the same way as in the notorious Palouse hummocky wheat lands of Washington and Idaho.

The light loams derived from forest soils are seriously affected by alternate freezing and thawing, and particularly on bare slopes are very vulnerable in this way. The action is somewhat that of pins being withdrawn from a pin cushion, single grains of soil being pushed upwards from below by the moisture freezing into what meteorologists know as "needle ice" which is merely frost acting on moisture held in the top layer of soil. The subsequent thaw leads to collapse and movement down the slope of a puffy disintegrated mass of particles. This is a frequent cause of erosion on Himalayan potato fields. Figure 17.

Fig. 17. Soil crumb at position 1 is lifted to position 2 by formation of needle ice. Gravity would bring crumb to position 3, but because crystal melts at its base, particle falls to position 4, then rolls or slides to 5.



(H. H. Bennett's "Soil Conservation" Figure 96.) By courtesy of Messrs McGraw Hill Co.

5. 17. Some observations upon snow-melt and its relative value under forest, on grass, and on bare ground have recently become available from Europe and America, and although not strictly applicable to our Himalayan conditions, are useful in a general way:—

(a) H. Burger's third report (1943) on Swiss catchment studies brings up-to-date Engler's classical studies of the forested Sperbelgraben and the grassland Rappengraben, and has been translated by Dr. A. L. Griffith (Indian Forest Records, Silviculture New Series, Vol. 6, No. 1, 1945). Rainfall following snow leads to dangerous flood peaks from the open pasture surfaces as compared with forest, the Rappengraben stream being always 30 to 60% higher than the Sperbelgraben immediately following such conditions. Burger differentiates between true melting of snow when the thawing of an existing layer of snow is caused purely by temperature rising and a thaw when warm rain accelerates the melting of the snow. The greater fluctuations of temperature in the open pasture cause correspondingly greater fluctuations in melting as compared with the forested catchment. During thaws the total run-off and the percentage of run-off to precipitation are both larger from pasture than forest. but the period is shorter.

(b) The behaviour of snow has also been studied by A. R. Croft and other workers in the Intermountain Forest and Range Experiment Station, Ogden, Utah, for forested catchments lying at 9000-10,000 ft. in the Wasatch Plateau, which is much more comparable with our Himalayan conditions of climatic extremes. The main gap in our knowledge is in what occurs from the time a deposit of snow begins to melt and the time when that part of the melted snow-water appears as stream-flow. Snow at 9000 to 10,000 feet begins to release water to the soil only late in the spring when it contains the equivalent of 24 inches of stored water and has a density of 40%; the melting rate averages 0.7 inches a day, and the melting only occurs between 2 hours after sunrise and half-an-hour before sunset: no melting was detected between sunset and and sunrise. Practically all melted snow entered the soil and there was no surface run-off, though penetration of gravitational water was unusually slow, since it was 12 days after infiltration began before it found its way down to 18 inches deep. Lateral movement through the surface layers is the course by which large quantities pass from these snow-beds to the stream channel in the late spring and early summer. The period May 12 to June 24 included the peak flow of the stream and more than half the total annual discharge of the stream, and this corresponded with the pressure of gravitational water in the surface soil layers. This

six weeks period provides the principal supply that sustains stream-flow for the remainder of the year (apart from monsoon storms). The complete absence of discharge derived from snow beds until this late spring melt is clearly brought out in the Wasatch measurements. There is a marked difference in the period of snow melt between south-facing and north facing valleys, a point which does not seem to have been considered for Indian projects; the peak discharge occurs for each valley for a period of about 30 days subsequent to the snow-melt penetrating to a depth of 6 feet in the soil underlying the snow-beds. The north facing valley maintained its summer flow for nearly a month longer than the south facing one. These results are all for an elevation of 9000 to 10000 feet, so we still have to work out what happens to the very wet snow which frequently falls at below 9000 feet in the Himalayas. Light falls are occasionally experienced as low as 3000 ft.

5. 18. *Snow-melt below 9000 feet.*—This matter was referred in 1937 to the International Commission of Snow, whose president, Dr. J. E. Church of the University of Nevada, gave an opinion which supported the writer's findings that the winter run-off depended on this low-level snow. This justifies my recommendations for control of run-off in the Uhl valley, whence is derived the water power for the Jogindarnager hydel project which supplies most of the Punjab's electric power. To present the matter clearly it is necessary to give an outline of the topography of the valley, the recommendations made, and the action taken so far.

The two streams, Uhl and Lambadag, together form a catchment of 150 square miles running from the main Dhauladhar at 17000 feet down to the junction of the streams at Brot at 5000 feet, whence the water is drawn off through a tunnel. A weak-point in the project has always been the very low winter stream-flow, and at the request of the Chief Engineer the writer undertook in 1936 a detailed erosion intensity survey, with the help of S. Puran Singh, Forest Ranger. On the basis of this survey, the details of which are given in para. 13.24g, recommendations were made (a) for the control of itinerant flocks in the alpine pastures, and (b) for the afforestation of the steepest areas of unterraced waste and badly terraced cultivation, which forms a belt along the lower slopes of both valleys, and which was found in the course of the survey to be the root of the trouble.

5. 19. Snow falling in the altitudinal belt below about 8500 feet is usually either mixed with rain or falls on ground already wetted by rain, though occasionally it finds the ground already frozen. Wet snow always tends to avalanche, and large areas

of bare grazing ground and of poorly terraced fields are swept clear of snow which lodges in the nearest stream-bed and melts very rapidly, the fields particularly being subjected to an enormous amount of erosion in the processes of thawing. Dr. Church has confirmed that for the Uhl conditions the crucial contour of 8500 feet does actually mark off the upper reaches in which the effects of frost are so marked that the whole of the land above this yields little or no winter run-off, whereas in the land below 8500 feet the available winter run-off depends upon the type of cover. Recommendations were made in 1936 that grazing be controlled and that 7000 acres out of the 22000 acre farm belt should be withdrawn from cultivation and grazing grounds, and afforested; the actual nett area under plough is about 4000 acres. The survey had shown that 55% of this belt were in a very serious state of erosion, largely as a result of uncontrolled snow-melt and bad terracing. Without the convincing data produced by this Uhl erosion survey it is unlikely that government would ever have agreed to the action now being taken, as the need for conservation measures below 8500 feet would never have been realised. (R. M. Gorrie: Conservation of Punjab Water Supplies Paper No. 216 in Punjab Engineering Congress Proceedings, 1937.)

5. 20. The itinerant flocks of goats and sheep were debarred from entry to the valley in 1943, and during the subsequent two seasons the recovery of the *kharsu* oak woods and the alpine pasture lands has been truly remarkable, in terms of the reduction of erosion and the reclothing of both forest floor and grass-land with a fresh growth of vegetation. Arrangements are now in hand (1946) for the acquisition under section 5A of the Chos Act of about 1000 acres of the steepest and worst terraced fields, which it is hoped will be rapidly afforested.

5. 21. Since these proposals were framed, more recent American, Australian and Swiss data have been published to confirm that a much greater and steadier winter water movement can be secured from a good grass cover than from bare fallow fields in regions where snowfall is seasonal, and the object in the Uhl should be to produce the best possible plant cover of grass, shrubs and trees on as much of the land below 8500 foot contour as can be acquired for the purpose.

5. 22. *Absorptive Value of Plant Cover.*—The value of a forest litter lies not so much in its capacity to absorb water as in maintaining the soil surface below the litter at its maximum rate of intake. It enables the soil column below to function at full capacity in transmitting water underground to the lower layers. To appreciate the value of plant cover let us consider the storage capacity of the ground below the soil. If we take the depth of

the water-table at 30 feet as an average for any foothills catchment area, the soil, subsoil and rock strata above the saturation line represent an enormous potential reservoir for flood water. The capacity of this top 30 feet far exceeds the heaviest possible rainfall, but the limiting factor which prevents it filling up is the poor percolation at and immediately below the surface. The top soil only becomes truly saturated in so far as it is separated organically or mechanically from the substrata. The water filling the pore spaces of the soil and subsoil must continue to be drawn down under gravitational force unless when it is confronted by an impermeable layer. If it meets such a layer the ground above this layer becomes gorged with water, but the soil column as a whole down to the water-table level is by no means saturated.

Let us now consider various types of soil in their capacity to maintain direct physical contact with this unfilled reservoir below them. The usual forest soil of the drier tropics and subtropics which has not been plugged hard by the feet of grazing animals has what soil scientists call a leached profile. That is to say it has a deep top layer of humus and powdery soil (the A horizon) from which the bases have been leached out and carried down deeper underground to form a more clay-like second layer (the B horizon). Below this again is a much more granular and porous C horizon of weathered parent rock. The second or B layer consists of such finely compacted material that the downward transmission through it by capillary action is slow. It is chiefly because of the honeycombing effect of live and dead roots, worm holes, animal and insect burrowing, that forest soil maintains its very high rate of intake.

Now grassland gives a different picture. Even in well protected grassland under a low and irregular rainfall the A horizon of humus and powdery material is much more shallow than in forest soil, and the grass presents less obstruction to surface run-off than forest cover does. The B horizon under grass may or may not be as dense as in forest—as a rule it is probably less dense, and in some cases the B clay layer is not conspicuous at all—but there is in any case a tendency for the rate of percolation to fall off. Compared with forest the grass has a poorer and shallower root system and there is less activity of worms, rodents, etc., so that its B horizon is less efficient as a sieve. The water storage space above this level is soon filled to capacity and in heavy rain the excess water is discharged as surface run-off. See Figure 2.

In the case of plough-land a plough-sole of smooth clay forms below the overturned soil when a heavy steel plough is used. With

the light Indian plough this sole is not so obvious, but nevertheless does occur. The passage of the plough and the treading of the bullocks tend to seal up any downward passage made by roots, worms or other animals, so that whatever sieve action the soil has when a crop is reaped is largely destroyed before the next one is sown. This sole may not be absolutely impervious, but the loosened soil above it has been separated mechanically from it by the plough, and with shallow ploughing the capacity of this loosened soil for absorbing rainfall is decidedly poor when compared with grassland or forest.

In the case of the typical Punjab village grazing land the plants growing on it are mostly stunted bushes and grass, but there is nowhere a complete plant cover. The soil is never allowed a chance to build up any A horizon because of the mechanical attrition of animals' feet. Heavy surface run-off causes a redistribution of the smaller particles which tend to plug the surface during each heavy storm, and the ground surface itself thus becomes less pervious after the first few drops have soaked in.

S. 25. *Moist and Arid Zones.*—There is a very great difference between our moist eastern and arid south-western climates. It is difficult to give a definite amount of rainfall as the dividing line between the two types, because the all-important factor is the quantity of moisture which gets into the soil. A 10-inch rainfall occurring in moderately heavy storms on flattish country and absorbed almost wholly by the subsoil is quite as good a proposition as 40 or even 50 inches occurring in almost cloud-burst intensity and falling on steep slopes which have already been deprived of their natural plant cover. Somewhere between these two examples the line dividing moist from arid has to be drawn. The two types differ not only in the quality and quantity of grass they produce, but also in their powers of recovery once the original plant cover has been destroyed. Under moist conditions two years' closure should be sufficient for badly misused grasslands to recover, but under arid conditions the process of recovery is very much slower. The nearer one is to desert conditions, either in the sense of true climatic and geographical position or through man-made conditions of increasing desiccation (in what were once richer plant communities, the harder it is to re-establish the previous ecological balance. The quality of the native grass crop and its ability to seed afresh depends upon soil texture and fertility, which in turn depend upon erosion conditions. Non-eroded grassland soil is much richer than eroded soil in lime, phosphoric acid and total nitrogen; its water-holding capacity is greater; the water required to produce a pound of forage is less; even with a notably smaller supply of water more forage is pro-

duced from non-eroded than from eroded soils. (Sampson, A. W., and Weyl, L. H., "Range Preservation and its Relation to Erosion Control in Western Range Lands." *U. S. D. A. Bull. No.* 675, 1918.) With each stage of depletion in plant cover the situation on grassland becomes more critical as regards both forage production and maintenance of the remaining plant cover. Deterioration in the local micro-climate brought about by destruction of the plants is reflected in higher temperatures, more rapid run-off, less absorption of moisture by the soil, greater evaporation, and worse damage to the relict plant cover by prolonged dry spells. (W. R. Chapline, "Range Research in the U. S." *Herbage Reviews,* March, 1937). The correctness of the American findings in this field of research is being corroborated by an increasing body of evidence from many parts of the Empire.

5. 24. *Causes of Deterioration of Soils.*—The soil even under arid conditions is not a dead mass of rock particles but is in a very real sense a living system. Micro-organisms are responsible for most of the chemical and physical changes which take place in a soil, particularly such changes as liberate nutrient elements and make them available for plant growth. The losses caused by both water and wind erosion are proved to be due not only to chemical and physical deterioration but also to the depressing effect which both types of erosion have upon micro-bacterial activities. Whatever methods we adopt for soil conservation and reduction of erosion losses, we must remember the influence of any soil treatment upon the micro-organisms. Badly eroded soils and those that have been exhausted by continuous cropping or persistent overgrazing are all alike in being "dead"—i.e. the activities of the living micro-organisms have been suppressed or the organisms themselves have been washed away or destroyed by the removal of the top-soil which also contains most of the valuable plant foods in a colloidal condition.

Most plough land in the Punjab *barani* tracts has been under intermittent cultivation for a very long time so that whatever organic remains were originally found in the soil and derived from the earlier forest or grassland, have been long exhausted. The farmer knows that if he does not manure his field his crop will be a poor one, even given good rains. He also knows that to get a good wheat crop he must follow a rotation of crops which include a leguminous crop such as gram or guara. Both farm manure and a leguminous crop serve to build up a more active and productive soil. Constant ploughing on the other hand serves to break the soil down to a dust, thus destroying the crumb or granular structure, which is a feature of old forest and grassland soils. Every time a plough or *sohaga* is used, countless

granules are crushed into powder, and this powder is so fine that when the surface gets wet with rain these minute particles clog the pores between the remaining granules, thus forming that impervious layer which is so important in increasing the run-off and preventing further infiltration into the lower levels.

5. 25. Crumb structure is best developed in soils which are saturated with lime and contain 3-10% organic matter of certain types and well distributed, but the only certain way to produce crumb structure is by putting the land under a grass or tree crop for a number of years. As explained in para. 4. 18 crumb structure is developed by the alternate shrinking and swelling of the mass of rootlets between which the soil molecules are gradually welded into granules. Hence these grassland soils are essentially different both chemically and physically from those that have been continuously ploughed; their organic matter provides a good supply of elements essential to plant growth, water and air are stored in proper proportions for soil bacteria to flourish, and in turn convert organic reserves into the simpler forms needed by plants. Root penetration is easy because the new roots follow the old ones through passages already formed. On the other hand in a soil in poor physical condition with the crumb structure no longer apparent, the effect of ploughing can be completely obliterated by a single hard-beating rain storm which puddles the surface into an impervious paste, chocking the young plant and drying round it like a vice. (*Jour. Amer. Soc. Agron.*, Feb. 1937, contains 3 excellent papers:—

R. Bradfield: Soil Conservation from the view point of soil physics.

E. E. DeTurk: Soil Conservation from the view point of soil chemistry.

S. A. Waksman: Soil Deterioration & Soil Conservation from view point of Microbiology).

According to Dr. W. S. Martin of Uganda the mere presence of a grass cover may not be sufficient to improve soil structure: the grass must be of a deep-rooted type which promotes the binding of soil particles into crumbs or minute clods. Rain can then penetrate rapidly to the subsoil; run-off and erosion are thereby diminished; and thus full use is made of a limited rainfall (*East African Journal Agric.* April, 1944).

5. 26. *Effect of cultivation on forest and grassland soils.*—Forest soils have a high "stability index" i.e. they are built up of complex crumbs or aggregations of the finer particles bound together by the colloidal action of moisture helped by active

changes brought about in the soil itself by bacteria. Bacteria are most active in forest soils and will continue to work in ploughed soil only if farmyard manure is frequently added and if the field is protected from erosion losses.

The ratio of volume to weight is low in forest soil and increases for the same soil as it alters under continued ploughing or erosion. Land under a good grass sod if not subjected to compaction by heavy and continuous grazing may develop a crumb structure even better than that of forest land, but heavy grazing makes the soil as impervious as land regularly cropped. If a soil is fundamentally poor, its crumb structure breaks down more quickly and more completely when disforested and cropped than do the richer soils. (R.B. Alderfer and F.G. Merkle in "Structural Stability and Permeability of Native Forest Soils compared with Cultivated Areas of the Same Soil Type". *Proc. Soil Sci. Amer.* 1941).

5. 27. *Alternatives to Ploughing.*—British workers (at Oxford S. J. Wright and at Rothamsted E. W. Russell and B. A. Keen) published results in 1938 which threw doubts upon orthodox ploughing as the best and only means of obtaining crops, the Rothamsted results showing that, for British conditions at least, a farmer could safely cut out or telescope the usual operations, but if he tried to prepare a seed bed for several years in succession without an initial ploughing, weeds eventually caused a drop in yield. E. H. Faulkner in *Plowman's Folly* (Univ. of Oklahoma Press, 1943) made a much sharper attack on traditional ploughing, maintaining that the remains of the previous crop stubble are of more value on the surface than ploughed under in an overturned furrow. Faulkner is right in that the use of the plough in a soil of powdery tilth allows the rain to seal the pores of the surface soil with consequent lack of penetration. It might also cause anaerobic decomposition of the buried organic layer, with toxic effects on the crop, but as a rule our Indian ploughing is so shallow that such an effect is very unlikely.

The main charge which the author of "Plowman's Folly" lays against the plough is that the act of soil inversion places crop residues and manures below the reach of the roots of the crop that is being grown. It creates a highy absorbent layer below the surface which through its large water-retaining capacity, interferes with upward capillary movement of soil moisture, in that it literally produces a "sandwich" layer between soil that is rapidly drying out above and moist soil below. This sandwich organic layer is easily eroded by water and wind, and consequently exposed to excessive evaporation from wind. An

artificial condition of drought exists between the buried organic layer and the sun-baked surface. In the long run the topsoil is entirely destroyed and lost.

The correct procedure to follow in cultivation, according to Faulkner, lies in the use of the heavy disc harrow which rips up and loosens the surface but does not turn under the grass-sod, stubble or cover-crop. Capillary uplift of water is thus arrested, and evaporation from the surface is greatly reduced by the blanket of mulch that covers it. Furthermore, the organic mulch is absorbent and prevents run-off during rains, hence loss of soil through erosion is lessened. His contention therefore is that we should increase the depth of our soil from the top downwards *rather than from the bottom upwards*, which is the method attempted when trash, litter and manure are buried deep. He advocates working from the top by piling up and accumulation of decaying organic matter which is Nature's way as seen in forest and meadow.

5. 28. Experiments reported by F. L. Duley and J. C. Russel in "Crop Residues for Protecting Row-Crop Land against Runoff and Erosion" (*Soil Science Soc. Amer. Proc.* 1941) show losses of soil and water from maize as:—

	Water run-off in inches.	*Soil lost in tons per acre.*
1. clean ploughed	2.25	2.5
2. keeping residues	1.10	0.6

The same workers published similar data in the *Jour. Amer. Soc. Agron.* for August 1939 which are reproduced below:—

Effect of leaving straw on ground from a previous crop.

Treatment.	Yield of air dry fodder. lb per acre.	% yield.	Moisture storage. inches below surface.
Ploughed and planted in furrows...	3890	100	0.23
Straw 2 tons per acre between rows	4870	125	1.42
" 4 " " " " "	5080	130	2.87
" 6 " " " " "	5350	137	3.20

Preserving of crop residues as a surface dressing for the next crop thus offers a simple and practical means of reducing erosion loss and improving the yield, particularly in our dry zone where

the reduction of evaporation loss is so important. But it is going to be difficult to persuade the average Punjabi cultivator to save any straw out of his scanty fodder supply to leave on his fields.

Whenever we advocate the use of contour ridging and *watt-bandi* in plough-land, the possibility of improving both the plough and the methods of cultivation should be fully tested on an experimental scale before any recommendations are made to the cultivators as a body. It is absolutely essential that any recommendations we make should be fully tested and thoroughly practicable for local conditions.

5. 29. *Erosion Pavements.*—In the absence of any vegetation it is advisable to retain any stones which may be *in situ,* such as are frequently found forming an erosion pavement of pebbles or small boulders on the outer Siwalik slopes. Such pavements are generally an indication that the area has at one time been cultivated without terracing, and will have to be cleared again for further cropping.

Experiments show that this erosion pavement is of considerable value in:—

(i) preventing further erosion of fine soil particles.

(ii) acting as a mulch in reducing evaporation and conserving moisture in the soil thus covered.

(iii) increasing the water absorption of the underlying soil. (Lamb and Chapman: Effect of Surface Stones on Erosion, Evaporation, Soil Temperature, and Soil Moisture, *Jour. Am. Soc. Agron.* of 7|43.)

5. 30. *Mulching.*—By mulching is understood any form of soil working of the surface layers, or covering up of the surface soil with any protective layer of cut grass or vegetable remains, by means of which the loss of moisture from the top-soil is reduced. Mulching by using the *khurpa* to loosen the surface soil at the time of weeding all ordinary field crops is well understood by the cultivator who devotes much time and work to this. Where horse-drawn or mechanical equipment is used, the crops are spaced in lines so that the machine can pass between or over them, and the operation is called *inter-cultivation.*

A layer of loose dry soil two to three inches thick on the surface of the soil serves as a mulch. Even after a fairly heavy shower of rain, the tracks of a bicycle ridden over a dusty road will be quite dry, showing that the water has been unable to soak through this top layer of dust. The farmer should therefore aim at providing this dry soil mulch on the surface of his

fields after every shower of rain. A shower will usually produce a surface crust and this must be pulverised by an instrument working to a depth of about 2 to 3 inches. Different soils will require different implements but the depth of these cultivations varies very little.

All recent research and demonstration of improved farming methods, particularly in the desert fringe where dry-farming is essential, have rightly emphasized the value of mulching, both through the old-fashioned breaking of the bare surface soil, as well as the newer ideas of putting down a cut grass cover between the rows of crop plants, or of preserving in the soil the undisturbed stubble and vegetable remains of the previous crop. The idea in each case is the same, namely to reduce the loss of moisture from the upper layers of the soil and so make more available for the crop plants. The application of this principle with all the local modifications necessary for each kind of farm crop and each type of soil and climatic variation can safely be left to the excellent series of leaflets produced by the Punjab Department of Agriculture, but there are applications of this principle which directly affect the soil conservation worker in grassland improvement and afforestation.

5. 31. In his paper on "The Afforestation of Dry Areas" read at the Indian Silviculture Conference of 1945, Dr. A. L. Griffith has advocated that (all sowings of grass and tree species should be done in lines running along the contours, rather than broadcast or in scattered patches as has been customary in most afforestation practice.) The object is to allow inter-cultivation of the bare soil between the rows, and to prevent the surface from remaining caked, as it invariably becomes after each rain-storm. (If the surface soil is never allowed to cake, not only is loss by evaporation reduced, but on nights of heavy dew this dew is fixed in the soil instead of being lost through evaporation. In the arid parts of the U. S. A. this fixation of dew is considered to be of the highest importance, and has been estimated as equivalent to doubling the rainfall). Soil working is recommended after every rainfall leaving a 3" radius untouched around each plant, but churning or breaking the caked soil to a depth of 2 to 3 inches. In the case of the shallow-rooted small transplant sets of bhabbar grass which is now being planted in a great variety of dry and unfavourable sites, this operation of mulching should be given a high priority.

The alternative of laying down a vegetable mulch for both tree and grass sowings is of considerable value and was strongly recommended by Dr. D. V. Shuhart of the U. S. Soil Conserva-

tion Service during his visit to our Attock division in July 1945, though his advocacy of it was more to protect the red marl slopes from direct erosion until the sown crop became established, rather than to conserve moisture. The obvious limitations of this method lie in the scarcity of chopped material in many of our very bare afforestation areas, and in the danger of removal by high winds which tend to bundle up into heaps any loose dressing of twigs or cut grass. This layer can be fixed by pegging down with stakes or stones.

5. 32. Comparative trials with broken earth mulch as against cut grass spread round the plants were done in Rakh Tawin in Tallagang tahsil of Attock division, and both showed a better plant survival than the untreated control, but the amount of cut grass available was poor to start with and much of it was blown away in spite of pegging down, and white ants also destroyed much of it, so that soil mulching by *khurpa* seems to be the better method of the two for most of our areas. On the other hand figures showing the value of cut grass litter in conserving moisture in the semi-desert afforestation areas in Arizona are most convincing:

Effect of grass litter on infiltration and percolation of rain water on granite soils in a semi-desert shrub and grass area.

Period.	Rainfall.	Surface run-off in inches from.		Infiltration into		Percolated to 6 ft. depth through	
		Bare surface.	Grass litter surface.	Bare	Grass litter.	Bare	Grass litter.
Oct. to March ...	22.96	6.06	2.50	16.90	20.46	4.88	7.69
April to Sept. ...	7.65	1.73	0.90	5.92	6.75	0.01	0.10
Total ...	30.61	7.79	3.40	22.82	27.21	4.89	7.79

(B.A. Hendricks in *Note No.* 96 March 1941 of South Western Forest & Range Experiment Station, Tucson, Arizona).

5. 33. *Green Manuring.*—The use of a green crop, preferably leguminous, for growing on fallow land in order to turn it under and build up a body of humus has reached its best development in Madras and Ceylon and is most readily successful with irrigation or a good rainfall, because the green manure ploughed in is of little use to the next crop until it has been rotted down. In dry farming it is apt to lie unrotted and in this dry zone it is liable to depress rather than improve the performance of the next crop. The main essentials are thus:—(a) a quick production of a bulk of vegetable fibre (b) the quick rotting of this crop,

(c) moisture storage, first for the green manure crop and secondly for the subsequent crop it is intended to help. See also 5. 38.

5. 34. *Kana grass as a green manure.*—In Uganda coarse cane grasses similar to our *kana* and *kahi* (*Saccharum munja* and *spontaneum*) are grown on a 3 to 4 years fallow, and then ploughed in after ensuring that the roots are dead. The manurial effect is somewhat slow and helps subsequent crops upto the 4th and 5th year after ploughing in. *Kana* even in the arid zone produces a good bulk of cane, leaves and roots with a minimum of moisture; it serves a twofold purpose, firstly by covering the fallow land with a mat of vegetation it reduces surface sheet wash during the resting or fallow period to a minimum, and secondly it provides a mass of humus which when it has been ploughed under helps to build up a better tilth, particularly where sheet erosion has already swept away the top soil and left only a clay or kankar subsoil exposed. Where *kana* is at all prolific its roots are so big as to present a real problem to the individual cultivator, with only his bullocks and a light plough, and even after burning the grass tops. A technique is required by which the grass is not burnt but is completely uprooted and the roots killed before being ploughed in. This could easily be done on a co-operative scale and using mechanised equipment. Burning must be eliminated as it is a wasteful destruction of much potential humus material. When the unrotted material is being ploughed under, the surface should be left as rough as possible, not broken down into a powder. In arid areas the response of the first crop after *kana* is ploughed in is likely to be disappointing, and in chapter XII, I have suggested that regular trials of a rotation of 4 years grass fallow then 4 years crops should be made throughout the desert fringe districts. (Desert Fringe Reclamation: *Indian Silvicultural Conference* 1945, author's own paper). The manurial problem in all *barani* land is acute and much work remains to be done in developing a sound system of green manuring which will be of value to the cultivator.

5. 35. *Preventing Erosion in Orchards.*—Conservation of soil and water are two of the most important factors in the successful production of fruit, and the quality of the fruit is also dependent on the amount of humus available. Contour planting and the terracing of new orchards can attain these three desirable factors. The planting and gradual terracing of an existing orchard can be effected in such a way that little extra labour is involved, for the subsequent working of the orchard is no more difficult than in a square planted one, and erosion and runoff of rain-water can be greatly reduced. On old-

established orchards the construction of soil conservation works often involve the removal of a few trees, but it has been found that the increased yield from the remainder more than compensates for this. The limiting factor for the successful cultivation of orchards in unirrigated land is moisture, and the more rainfall that can be retained in the soil for utilization by the trees during the dry season the better. If the orchard is contour-ridged already the absorption of water by the soil can be improved by the excavation of pits at intervals behind the ridges, and filling them with weeds and trash, or alternatively by the construction of low banks at intervals at right angles to the contour ridges, but naturally the tops of these banks must be considerably below the top of the contour ridges themselves as they are subsidiary to the main contour plan.

5. 36. When starting entirely new orchard planting the following types will be a useful guide:—

(1) Bench terraces constructed prior to the planting of trees. As this method is relatively costly it is mainly confined to small orchards on steep slopes.

(2) Specially designed contour ridges where the slope is not steep enough to justify bench terraces, but where the slopes of nalas are too steep for ordinary field crops and are therefore taken out of the field plan to be roughly terraced either by bulldozers or by hand and dedicated to fruit trees and grass production. See Fig. 18.

(3) Normal type contour ridges—On relatively flat slopes the ordinary type of contour ridge with normal spacing (see para. 3. 15) can be constructed and the trees planted in rows on the contour between the ridges, either accurately on the contour or in rows parallel to the ridge, immediately downhill.

5. 37. While these measures will retard the runoff of storm water, they will be of little value unless the moisture-retaining capacity of the soil itself, which is almost entirely dependent on the amount of humus present, is improved. Repeated cultivation will damage the soil structure if the humus content is low, and scraping with hoes or ploughing will have the effect of creating an impervious surface layer which not only reduces the rate of penetration of water, but also prevents the excess of air to the roots of the trees, and is therefore harmful.

5. 38. Instead of clean cultivation it is preferable to allow weeds to grow, and to control them by cutting and slashing. The

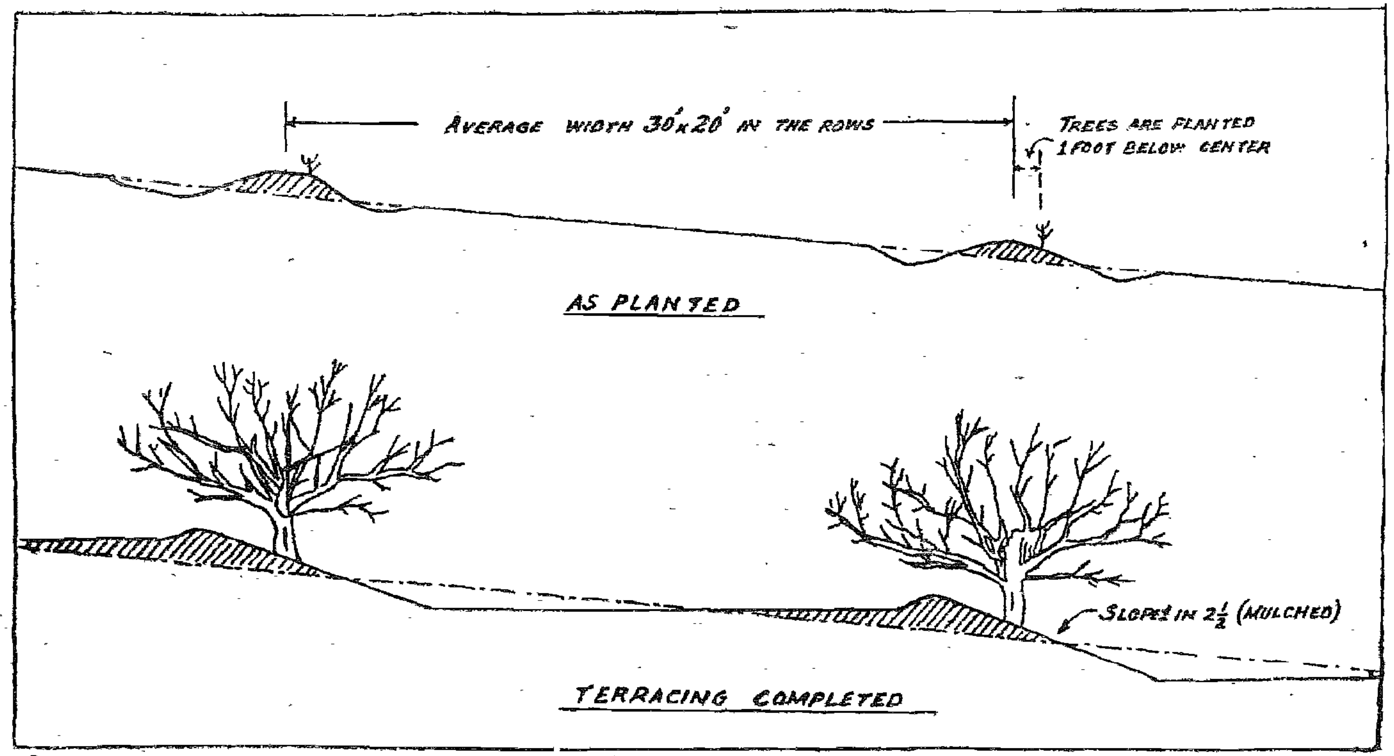


FIGURE 18

Conversion of contour ridges to bench terraces, trees planted on down-slope. A suitable practice for moderate to steep slopes. Para. 5.36.

disadvantages, however, are that the weeds utilize much moisture and may also harbour pests. The best system of all is the spreading of green mulch between the trees. The usual rate of application varies from 3 to 6 tons per acre dependent upon the size of the trees, but even heavier applications have been used with added benefit. A suitable mulch crop can be grown on the vacant strips of land between the rows of trees. The advantages of a mulch are that it immediately increases the rate of penetration of rain-water, and also reduces evaporation. The reduced rate of evaporation directly causes an improvement in the soil structure, and later the gradual decay of the mulch forms humus which renders the soil still more friable and retentive of moisture.

Leguminous crops are to be preferred for the mulch as they supply much needed nitrogen, and *sunn* hemp if cut before it is high enough to choke the trees is excellent. Sunflower, jaint, munga, Sudan grass or other heavy yielding crops are also quite suitable. Considerable damage can be done to trees, especially when young, if the intercrop is planted close to the trees or allowed to grow so high that it competes with the trees for light and air. It is for this reason that a wider spacing between the rows is recommended, and even then the intercrop, if a tall variety, should be restricted to a narrow strip midway between the trees. It should be realised that orchards should be given the same consideration as any other crop that is expected to do well. Orchard trees are unlikely to continue to produce good yields if the soil is not fed or is allowed to erode.

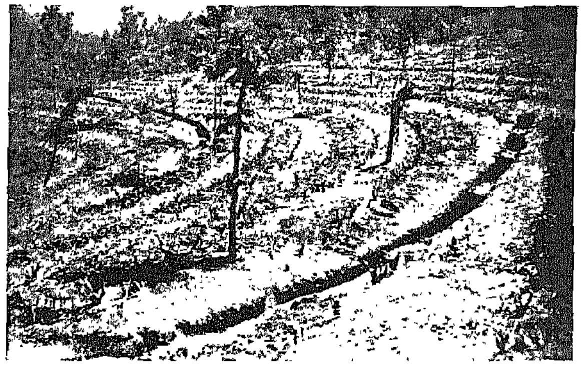
5. 39. *Erosion Control in Commercial Plantation Crops.*—Tea is so far the only major commercial crop of a permanent nature in Northern India and is confined to Kangra and Dehra Dun. The old Kangra gardens have been broken up into small holdings, and like similar holdings in Ceylon are in an appalling state of erosion, individual plants being almost invariably so exposed that the roots form an inverted umbrella in a clay subsoil from which all the top soil has already been lost.

The Tea Research Institute of Ceylon has abandoned the search for a perfect leguminous ground-cover crop, as their *Indigofera entdecaphylla* has not come up to expectations, so they now advocate *selective weeding.* The idea is that a low ground cover of small weeds can be tolerated, provided the larger and greedier feeders are eliminated by weeding, bruising, uprooting, or cutting back. The common practice of scraping the surface to keep bare soil exposed and entirely clean of all plant growth between the tea bushes is being discouraged, as it renders it impossible for the soil ever to improve in humus content, and renders

PLATE 7 (i)

Tea bushes in rows planted along an accurate contour with a drain cut on a slight downward slope, thus crossing some of the tea rows. The tea bushes are newly pruned.

Tea Research Institute at Talawakele, Ceylon.



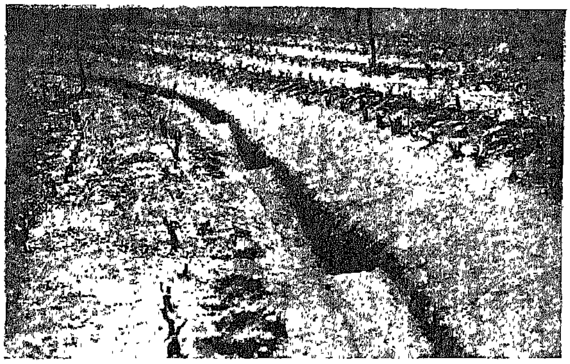


PLATE 7 (ii).

Newly pruned tea bushes with drain cleared of silt which is dumped around the tea roots the steps in the drain being carefully maintained with a reverse slope.—Para 5.39.

PLATE 7 (iii)

Killefer ditcher plough digging an open ditch, eminently suitable for contour control of run-off on gentle slopes or digging drainage channels on water logged land or diversion ditches for redistributing flood water, Para 8.8.

top dressings of artificials quite useless because they are washed away at once. *In Ceylon drains are laid out on a gentle gradient* and are stepped at intervals, the scrapings being always put back around the plants. (see plate 7).

As old tea has never been planted on accurately contoured terraces, complete contouring would entail almost complete re-planting. *This can be avoided by making a small palisade or* wattle of any available sticks to connect up any tea plants which are growing on a contour and thus link up 3, 4 or more plants with a contour hurdle.

Chapter VI.

RUN-OFF CONTROL BY FIELD DRAINAGE AND GULLY PLUGGING.

6. 1. *Varying Intensity of Erosion and Run-off in Different Types of Land.*—It is exceedingly dangerous to generalise about the prevalence of erosion for any given climatic conditions. Geologically it will generally be found that soft shales and sand-rock erode much more readily than gneiss or granite, and these again more readily than limestones, but certain strongly indurated sandstones, such as the Gurgaon low hills west of Delhi are very resistant. Much depends on how rock is treated; Asoka's edicts carved on gneiss two thousand years ago are as good as new, but the same rock overlain by soil containing humic acids from tree roots has rotted to great depths. The weathering of most rocks is accelerated by acidified seepage water, not by pure rain water, and the necessary acid is contributed by any plant cover.

Erosion is less where the rainfall is well distributed and it is now commonly recognised that erosion can have most serious consequences in arid tracts. A heavy monsoon has more effect upon unterraced fields than it has on neighbouring grasslands, whereas in arid climates the smaller area of fields is more carefully terraced, but the neighbouring grazing grounds are more vulnerable to infrequent heavy downpours. This may serve to explain an anomaly that occurs in run-off intensities. American figures worked out by Ramser and frequently quoted show the averages in cubic feet per second per square mile, and in contrast tentative data of the same sort for Indian conditions are shown below.

Run-off in cubic feet per second per square mile.

America.	Cusecs	*Punjab.*	Cusecs.
Hilly timber 10-30 per cent slope ...	300	Terraced rice fields	60
		Foot hills afforested & with soil-catching small dams.	120
Hilly pasture	620	Foot-hill scrub forest closed to grazing	700
Hilly cultivated	1040	Foot-hills scrub forest open to grazing	1100
		Foot-hills disforested and heavily grazed	1600

(Current Science, August 1937. Author's review of Q.C. Ayres' "Soil Erosion".)

6. 2. The American farmer using a motor tractor keeps his fields large, and so the run-off from broad slopes of bare plough-land is greater than from his paddocks of comparatively well-clothed pastures. On the other hand, the Indian peasant farmers have their fields in tiny and often well-terraced units which catch and hold the rainfall, whereas their grazing grounds are so misused and so badly protected with a mutilated plant cover that the run-off from them is far heavier.

Reliable data for run-off and erosion, and also for rainfall intensities and storm behaviour, are lamentably scarce even for our most important catchments, and a great field of work awaits the next generation of Punjabi research workers.

6. 3. *Erosion Losses from Plough-land.*—In areas of rainfall too heavy to produce natural grasslands as an ecological climax, the processes of destruction are somewhat different though the end results, namely impoverishment and desiccation, are the same. The power of recovery and re-entry of vegetation on to bare ground with a favourable rainfall is immense; palatable grasses are usually only an intermediate stage in the process of recovery and are soon ousted by bush, tree, bamboo or other heavier plant cover; but while the soil is actually exposed the soil losses must obviously be heavier. Previous measurements from United States Department of Agriculture run-off plots showing losses as heavy as 150 tons of soil per acre per annum from bad cultivation methods on steep slopes were looked on by many Empire workers as being freak figures, which could not be generally applied, but the Sholapur figures published by N. V. Kanitkar in "Dry Farming in India" show very clearly that such losses are all too common and are not confined to the poorer types of cultivation or to any particular type of climate, or to steep slopes.

6. 4. Observations of potato cultivation in the Western Himalayas show that the average life of a potato field with downhill ridges dug out on an already steep slope is from four to eight years, after which it is fit only for less exacting crops or is allowed to deteriorate under heavy grazing until it finishes as a scree of stone entirely devoid of earth or plant cover. This is closely akin in destructiveness to the shifting cultivation of the aboriginal tribes in many other parts of the world, but in the Punjab it has received an entirely false stamp of respectability through being incorporated under so-called "permanent revenue settlements", which have given it an air of stability which in truth it does not possess.

6. 5. Kanitkar's Sholapur data for run-off plots with a fall of 1.18% (1 in 85) in fields of Deccan Trap soil with a rainfall averaging 26″ falling on 41 rainy days is for a milder and less extreme climate than the Punjab, but even so the losses in run-off and erosion are much higher than one would expect from nearly level land. Losses by run-off in the first half of the monsoon were only 10-14% but in the latter half rose to 24-34%. Only showers of ½″ or more penetrate below the top-soil so that light showers are lost entirely through evaporation. From a series of comparable plots under different soil covers and soil working, annual average soil losses varied from 0.64 tons per acre for grass to 43.99 tons per acre from thorough cultivation under *jowar*. In a third plot treated by scooping holes (somewhat on the lines of a basin-lister machine but making holes of a much smaller capacity) loss was 16.40 tons, while a bare fallow without weeds lost 18.04 tons. Shallow cultivation lost 30.19 tons as compared with deep cultivation loss of 43.99 tons, because of exposure of soil in the early stages of the crop and also because of inter-cultivation which had loosened the soil to a great depth and thus made it more vulnerable to prolonged rain. In the deep *jowar* cultivation annual losses over the 7 year period of observations varied from 0.17 to 133.48 tons thus confirming that erosion losses are not necessarily heavy every year but are spectacularly heavy only with single storms of great intensity. Out of the 7 years, two years showed exceptionally heavy losses; they were not the years of heaviest annual rainfall but they did have the largest number of intense storms. From the average annual rate of soil loss from these plots it was computed that 8 inches of surface soil is lost in from 20 years to 54 years for different soil workings, as compared with grass sod in which it would take 1384 years to lose 8″ of soil.

6. 6. *Erosion Losses from Waste land.*—Very few reliable run-off figures for forest and grassland are now available for Indian conditions. A technique of volumetric analysis of water and silt was worked out by the Punjab Irrigation Research Institute staff at Madhopur in 1936 for a type of small isolated plot of undisturbed soil 3½ square feet in area, and this method has been followed in forest plots at Nurpur in Kangra district. A battery of six plots gave three pairs of (i) grass, (ii) grass and shrubs, and (iii) bare soil, on a slope of 1 in 4 on an eroded hill-side of poor Siwalik sandstone. The grass cover over all was distinctly poor, as it was recovering slowly from previous heavy grazing. The bare plots contained a little grass which was kept clipped back with scissors. They thus simulated local grazing conditions to some extent, though they have not reproduced the

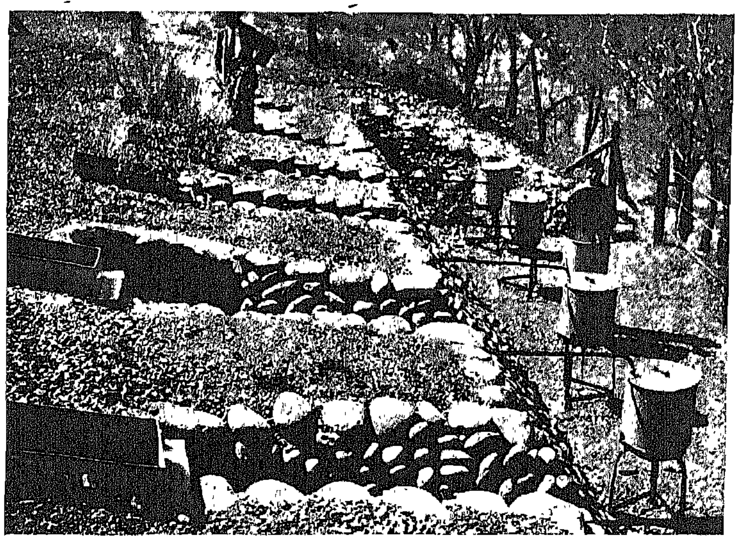


PLATE 8. (i)

Field Measurement of Run-off. See Para. 6.6. for description of the sets of small plots isolated by tin guards, from which comparative data were obtained for Kangra grasslands.—Para 6.6.

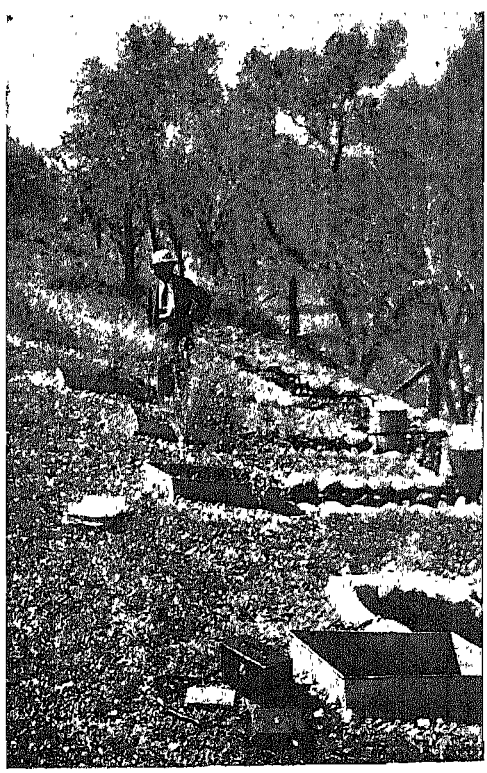
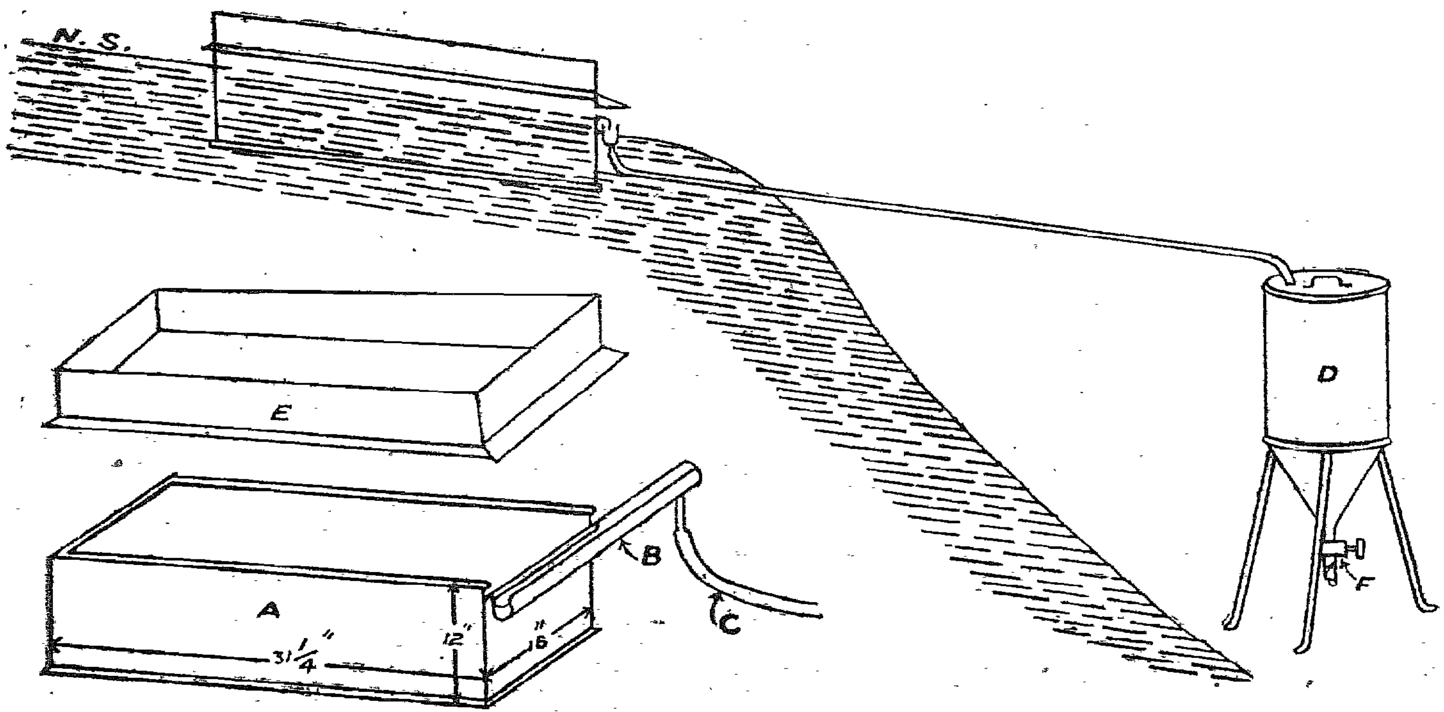


PLATE 8. (ii)

FIGURE 19

ARRANGEMENT OF FIELD APPARATUS FOR SOIL EROSION EXPERIMENTS.



destructive tramping action of cattle scrambling on a wet and greasy hillside; and the run-off from grazed areas must therefore be considerably heavier than the figures now reported. The result of the first monsoon's catch was as follows:—

Nurpur Plots, 1937..

	Grass 80% cover.	Grass & shrubs 90% cover.	Bare soil, grass clipped every 3 days.
Percentage of rain which ran off :—			
Out of total of 46 ins. on 32 wet days during July-October 1937	7%	25%	25%
Out of total of 5¼ ins. in 4 hours, the heaviest single storm	2.2%	1.7%	6%
Weight of soil lost per acre :—			
Carried away on 32 wet days	3,500 lbs	3,900 lbs.	18,500 lbs.
" by a single storm 5¼ ins.... ...	260 lbs.	307 lbs.	3,511 lbs.

(R. M. Gorrie's "The Problem of Soil Erosion in the British Empire with Special Reference to India". Royal Society of Arts Journal, Vol. 86, No. 4471, 1938, and reprinted in Agriculture and Livestock in India. March 1939.)

These figures give one food for thought when it is realised that in a single storm the uncovered plots lost soil at the rate of 1½ tons per acre. They are definitely conservative for the average village grazing lands which suffer from trampling of cattle. The ordinary grazing lands also suffer from the accumulative action of shallow gullies cutting the surface on long slopes, a phase of erosion which is, of course, not reproduced in our small square plots.

6. 7. The same apparatus was later installed at Polian in Hoshiarpur on the pebbly uplands of Garhshankar tahsil near where our three small catchments were measured for total run-off, and gave the following data for individual rain storms, comparing run-off from bushes, grass and bare soil.

Date.	Rainfall in inches.	Duration of storm.	Intensity in inches per hour.	Run-off of rain (cubic cm.) bushes	grass	bare	Silt loss (gm.). bushes	grass	bare
22-7-40...	3.28	10 hours	0.32	1350	12200	14525	7	18	95
1-8-40 ...	2.67	6 "	0.44	700	8900	16800	9	34	95
2-8-40 ...	1.75	2 "	0.88	425	8625	10500	5	17	41
8-8-40 ...	1.71	1½ "	1.14	925	7150	8700	13	22	40

These figures show clearly that although a thin grass cover is much less efficient than bush growth in holding back run-off it does function well in terms of preventing silt loss.

PLATE 9 (i)

The outer Siwaliks contain many suitable sites for small dams which will pond back 30 to 60 acre-feet of water behind a 15-25 foot earth dam with a clay or cement core and a pukka spillway. 1 acre-foot = 43560 cft. water.—Para 8.7.

PLATE 9. (ii)

A massive masonry weir of a type popular in Rawalpindi district & used there to block a nala bed & hold up silt to form a field behind. As the silt collects the height of the masonry of sill is raised. The field behind shows fine crop of wheat. Note water collected both above & below the dam.

For details of construction and working of this run-off measurement equipment see author's article in *Indian Forester* for Nov. 1937, from which Plate 8 and Figure 19 are copied.

6. 8. *Maintenance and repair of Watts and Bunds.*—The proper handling of surplus field drainage follows logically after the contouring of fields and has been dealt with in para. 3. 19 onwards, but in our soil conservation work we shall often be forced to deal with the accumulated run-off from large blocks of fields which have not yet been fully contoured, or as in the Salt Range where formerly good *wattbandi* has deteriorated to such an extent through breaching that the field drainage is, completely out of control. In such cases the repair of a few earth bunds near the bottom is not likely to be more than a temporary palliative, and repair of *wattbandi* must start at the top.

6. 9. *Rat damage.*—Having got the system of *watts* in good order, maintenance depends largely on each cultivator's own initiative to do seasonal repairs at the time of ploughing, but in many areas rat damage is so persistent and so serious that departmental help must be given to organise the destruction of rats. Soil conservation divisions are now equipped with poison pumps and a few subordinates have been trained by the local Extra Assistant Directors of Agriculture in the use of these pumps, but continuous effort will be needed before we have established this work as a routine.

There are a number of commercial poisons on the market and they fall roughly into 2 main classes, others being home-made recipes:—

1. Gas-producing chemicals such as cyanide which can be pumped down the rat burrow out of a pump or flit-gun.
2. Poisons which are applied as a paste to pieces of food or are mixed in proportion with *ata* into balls of dough.
3. There is a third group of home-made poisons depending on the use of some locally common poisonous plant, but these are often a waste of time and money as they are not powerful enough for our purpose. The best home-made poison is powdered glass which can be added to food baits in balls of *ata*.

The use of gas poisons requires care and skill and the instructions of the makers must be carefully observed. All burrow entrances except one should be blocked with rammed earth before the gas is pumped down the only one left open.

6. 10. *Construction of Outlets.*—Where light sandy soils occur, rainfall is rapidly absorbed, and practically no drainage problem arises. But where the prevailing soil is non-porous clay-loam and clay there is danger not only of the heavy downpours stagnating on terraced and *watted* fields and so damaging *kharif* crops, but also of the watt bursting. In friable calcareous soil, the fields may sink through underground collapse. To obviate all these a field-to-field drainage system is imperative; and the natural drainage lines should be utilised to carry off the surplus storm-water.

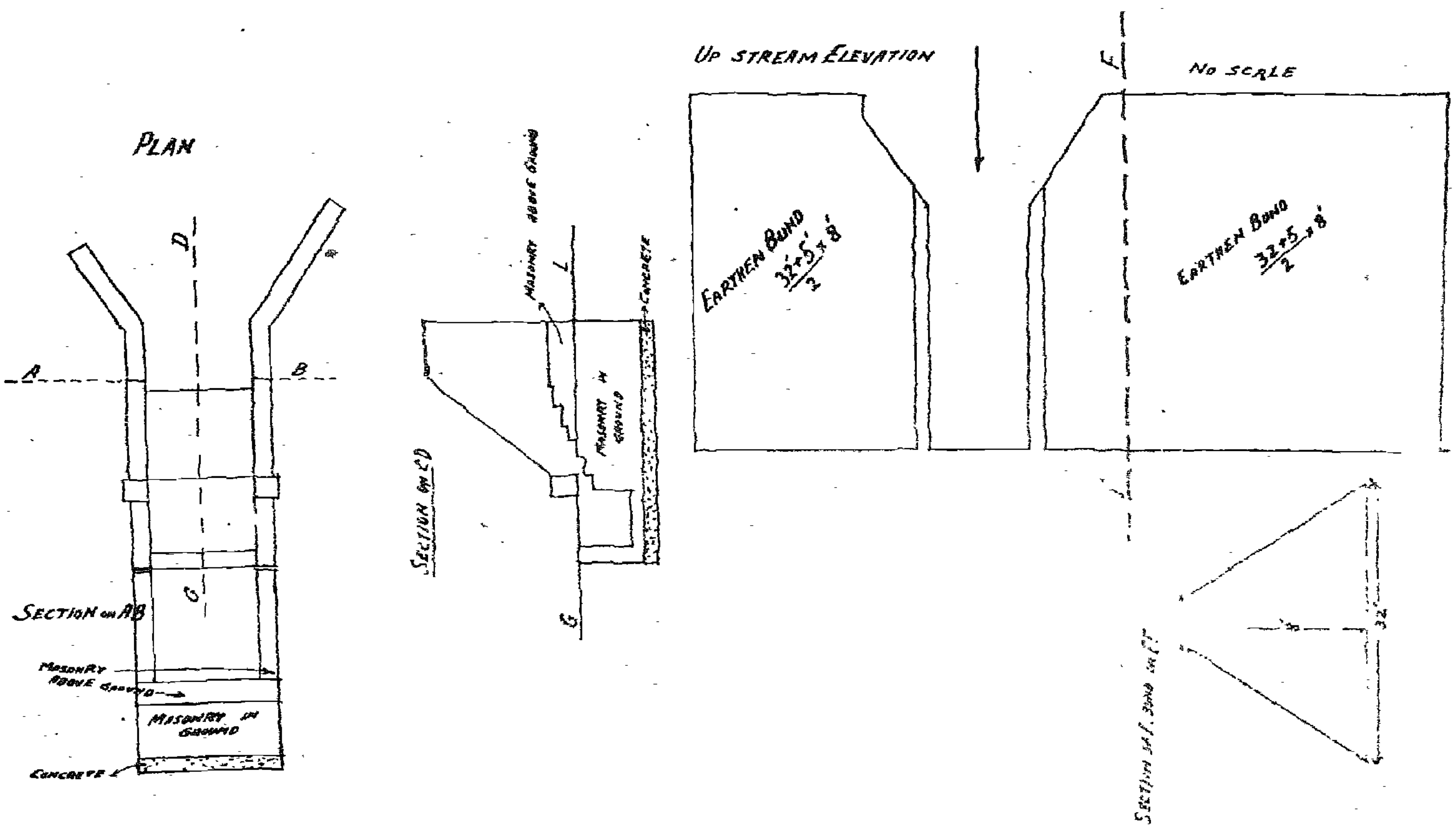
6. 11. The main drainage channels should be protected by vegetation as described under *dub* grass in para. 4.21c and *kacha* outlets should be thickly matted with this grass in the case of low terraces, in order to drain out surplus storm water which cannot percolate rapidly, particularly on impermeable soils. This would prevent breaches in the *watt*, formation of gullies, subterranean scouring and damage to crops from standing water. *Kacha nakkas* of grass should be made when the terraces are up to 3′—4′ high.

6. 12. For drops greater than 3 to 4 feet, masonry outlets will consist of a single layer of bricks laid in mud or lime mortar and be cement-pointed on the outside. Every outlet should have its mouth through the *watt* about 3″ higher than the general level of the field, in order that an average depth of 3″ of water may stay on in the field for continued percolation after cessation of rain. An apron of bricks on edge should be laid to carry the water down from this sill, and at the foot of the sill a stilling pool to prevent under-cutting of the structure should be ringed in with a low wall 2 bricks thick.

6. 13. *Escape Weirs.*—A slightly more ambitious type of escape or outlet is required whenever the volume of water to be passed down exceeds say 5 acres of fields and therefore entails something in the nature of a weir. The use of this word also conveys the idea of raising the water level and thus constitutes much more of an obstruction than the normal field outlet, and in our technique is reserved for a masonry dam or sill big enough to dam back an appreciable quantity of water and thus start a deposition of silt which ultimately becomes a field.

6. 14. Any broad shallow channel with a low gradient and a catchment of from 5 to 200 acres can be fitted with a stone or brick weir which will cause ponding back of the run-off, and if erosion is rife, this quickly leads to the formation of a terrace of silt which will not be quite flat but will have a lesser gradient on its surface than the gradient of the stream bed. When top soil is being removed as a result of bad cultivation or heavy grazing,

FIG. 20. WEIR OF BRICK OR MASONRY FOR EARTH BUND FOR CATCHMENT OF 10 ACRES AND UP TO 100 ACRES
PARA G.12



the silt caught will be exceedingly valuable, and as a commercial investment a weir to form a fresh field may appeal to many who are not normally interested in agricultural development. On the other hand there will be many disappointments due to the ponding back of sterile sand if erosion is so severe that the valuable quota of fine top soil has already been removed. In Hoshiarpur they say that a cho starts as gold and finishes as brass.

6. 15. There is nothing essentially different in design between a check-dam and an escape weir, and the construction of both is essentially the same, consisting of a strong plinth below the normal stream bottom, and above this a wall curved upstream so that pressure of silt and water will tend to key the arch into stability. The lip is also vertically curved so as to allow the passage of a good body of water without running any risk of overtopping on the flanks. Unlike the check-dam however the weir is usually intended to be carried to a higher level as and when the field has been partially silted up, and typical weirs in Rawalpindi have been raised many times. The bund on its flanks must be kept well above the level of the masonry; a frequent source of failure is through a cattle path being used so continuously that it eventually forms a gap in the bund lower than the masonry sill of the weir, when of course the bund is breached. To calculate the correct size of apperture see para. 9.42 for the run-off from small catchments & para. 9.39 for formula for width and depth of the weir lip. Calculations should invariably be checked by an experienced officer, either forest or Irrigation Branch.

6. 16. *Gully plugging.*—The use of this word was confined originally in American parlance to the packing of the vertical fall at the head of a gully which was cutting back into the higher land behind it. This was usually done by filling the whole hollow with brushwood and weighing this down with stones and logs, or pegging it with driven posts. Latterly however it has been realised that a vertical face left bare will continue to cut back, and the conventional method now is to cut the vertical lip right back to a reasonable slope whose face can be pitched with stone. This of course is not feasible in our worst ravines which contain many thousands of vertical head falls of anything up to 100 or even 200 feet sheer drop. Like most new words "gully plugging" has come in for a good deal of abuse and wrong application. It is now loosely used to cover any system of check-dams in the upper reaches of a torrent.

6. 17. The reference to gully-plugging on page 39 of Sir H. M. Glover's "Erosion in the Punjab, its Causes and Cure" is somewhat misleading, insofar as he applies this word to both contour trenching and check-dams under the heading of "Works in the Catchment Area", but separating it from "Field Engineering", under which title he strongly advocates the use of mechanical equipment for the terracing and reconditioning of eroded lands. The very expensive use of bull-dozers to recondition ravined lands is quite unjustified unless the catchment of the torrent responsible for gullying in the first instance is fully controlled, because the new terrace will never be secure or permanent until the whole of the run-off has been tamed. Even where such concentrated reclamation is not being undertaken, and down-stream work is confined to orthodox torrent training work in the flat lands below, as in the Bachoi-Maili working plan, it is essential to obtain the optimum run-off control in the upper catchment. In fact it is safe to say that the almost complete canalisation of Bachoi-Maili *cho* is due to the check-damming in the hill catchment. The improvement of plant cover must assuredly be our main objective, and in the case of penniless and small individual states in the hills it is probably the only feasible method, but the use of check-dams cannot be ignored and must be learned by all who wish to stop erosion.

6. 18. The antipathy common amongst British officers to the adoption of so-called American practice should be discounted by the fact that check-dams for stream training within the hills has been in use in Switzerland, France and Austria for at least a century, and these countries as well as America have gained much experience which to some extent is applicable to Punjab conditions. The following observations are based on that experience:—

The more intense the storm and the higher the flood peak the smaller will be the percentage of reduction brought about by any form of gully plugging. The maximum reduction of flood water will be through the systematic plugging of only certain tributaries, leaving others in their natural condition, and thereby spreading out over a longer period the arrival of these tributaries' contribution into the main stream. The effect produced by this "telescoping" of contributions will obviously depend upon the shape of the catchment, and will show maximum efficiency in a broad fan-shaped catchment whose watershed ridge is a complete semi-circle or broad and regular arc. It will be least effective in long narrow catchments with a number of small feeders, which join their stream well spaced out. It should be possible to get an indication of the effects of such work by building a model

of the catchment area, roughly scaled both vertically and horizontally and with the distribution of plant cover simulated in miniature and using rain simulated by fine spray.

6. 19. The path of a storm is also of importance, and the worst direction is that in which a storm with a broad front impinges upon a large section of the watershed ridge in the same period in time. In our foothills the worst storms are those of the monsoon which sweep in from the plains and discharge the main force of their storm upon the outer foothills at a height of 2000 to 9000 ft. thus filling to maximum capacity every *nala* in a whole section of foothills. The greatest storm intensities probably are experienced at about 4000 ft.

6. 20. The most effective agent in reducing flood peaks and the carriage of debris from upstream is the plant cover in the catchment itself, so that whatever upstream engineering is undertaken must always keep this point in view. The main justification for all forms of gully plugging or check-dams is to promote plant growth on the banks and in the stream-bed itself, which in turn will help to decrease the force of the flood. The presence of plant growth will in itself be the best guarantee against the further cutting of deep V-shaped gullies in the path of the stream.

6. 21. *The Functions of Check-dams.*—The uses of check-dams may be summarised as follows:—

i. by direct storage of water and debris.

ii. by acting as drops and thereby reducing the normal grade, thus restricting the velocity and reducing the silt-carrying capacity of the stream by making it drop its load of coarser sand.

iii. by widening the channel and thus stopping deeper V-shaped cutting.

iv. by increasing the wetted area and consequently increasing percolation and ground-water storage.

v. by encouraging tree, bush and grass growth on this area.

vi. by preventing further bank erosion.

The following paragraphs deal with these 6 points in detail:—

i. *Direct storage of debris.*—The steeper the slope of the *nala* bottom the less material will be caught behind a check-dam of a given size. Provided a firm bottom is available for building on, quite steep *nala* heads, upto say 1 in 2½, can be plugged. The limiting factor is usually however the instability of the bottom, and where this is obvious, it is better not to attempt to plug slopes

as steep as this, but to be content with putting a single heavier bund or check-dam where the steep slope starts to level out to say 1 in 6 or 1 in 8.

When each check-dam is full to capacity with debris any additional debris carried by storms will obviously continue to move downstream, but it will do so at a greatly decreased pace, and to a great extent be deprived of its power for further damage. The debris actually held up acts as a sponge which remains moist for many days and even weeks after each storm and this helps to establish a more permanent water storage which is available to plant growth.

ii. *By acting as 'drops' to reduce velocity.*—Each check-dam forms a step over which water can pass and thus reach a lower level without causing damage. For a given rate of rainfall a definite amount of run-off flows down each tributary. Check-dams do not appreciably reduce the peak flow in each tributary but they delay the time of arrival of that peak in the main stream, so the maximum benefit obtained by gully-plugging will therefore be obtained by chek-damming certain branches out of closely associated groups of branch *nalas.* Each catchment thus forms a problem in itself. There can therefore be no standard rules as to how far the expense of check-damming is justified. The greatest reduction in velocity occurs where the stream flow is small, and where the channel already has a wide cross-section. The flatter the slope of the stream bed the greater will be the stilling effect of each check-dam.

iii. *Stopping further cutting.*—The efficiency of a check-dam in a stream channel which is underlaid by soft rock or soil will depend upon the structure's permanency and stability, and it is by this means alone that a subsequent cutting regime can be prevented from recurring. The actual design and construction details of each check-dam are far more significant in beds where cutting is liable to be resumed than where the stream has already cut right down to bed rock.

iv. *Increasing percolation.*—One effect of a check-dam is in the broadening of the area in which downward percolation of moisture takes place in the stream bed itself. Particularly in streams which have no great overflow areas in their course, the increase in the wetted area of sandy bed is of importance. The more that percolates into the arrested silt the better the hope of re-establishing a permanent flow.

v. *Promotion of plant growth.*—The real object of check-damming is to establish a better plant cover, not only along the banks but also in the stream bed itself, where the presence of

plant growth will increase the ponding effect and further delay torrential run-off. The application of planting to the actual stream bed in the narrow gorges of the hills must not be confused with the use of vegetation in the lower and flatter outfalls on the plains. In the latter case plant growth in the actual stream bed is objectionable because it will interfere with complete canalisation.

vi. *Preventing bank erosion.*—One of our most difficult problems is to prevent sloughing of material from steep faces of raw earth in the hills and also in the plains below. The meandering of the stream, which follows certain laws of behaviour, will always tend to cut deeper and deeper into higher banks on the outside of any curve. The best way to prevent this is to slope it back and revet the new sloping face wherever possible, and thus prevent the stream from removing soil from the base of the exposed face. (vide para 11.3).

6. 22. *Check-dams; materials and construction details.*—The extensive use of the check-dam as an aim in itself is to be deprecated. The essential purpose of check-dams is to enable vegetation to invade and take charge of whatever silt is accumulated by means of each dam. The word check-dam is usually taken to mean any low structure which will check the pace of the water and so persuade it to deposit part of its load of silt and debris, but allow the main volume of flood water to flow over it.

6. 23. In our Siwalik work a convention has been established that check-dams of dry stone must be set close together in multiple series, starting from the very top of each branch *nala*. The spacing is important; the work should not be undertaken at all unless sufficient funds and labour are available to build plenty check-dams. The top of the next downstream should be on the same level as the *nala* bed level (*not* the foundation) of the dam next above it. This should be continued for each one, working downstream until the width of the *nala* reaches 20 ft. or until the catchment area of that *nala* is one square mile (640 acres), *whichever is less.* The reason for this convention is that beyond either of these limits the force of the flood is likely to destroy anything less solid than cemented masonry. Beyond this point, therefore, the siting of any further dams will depend upon the existence of suitable sites for structures which will pond back an appreciable quantity of water as well as silt; these will be dams, and not check-dams. The material for check-dams will depend upon whatever is available locally and no check-damming

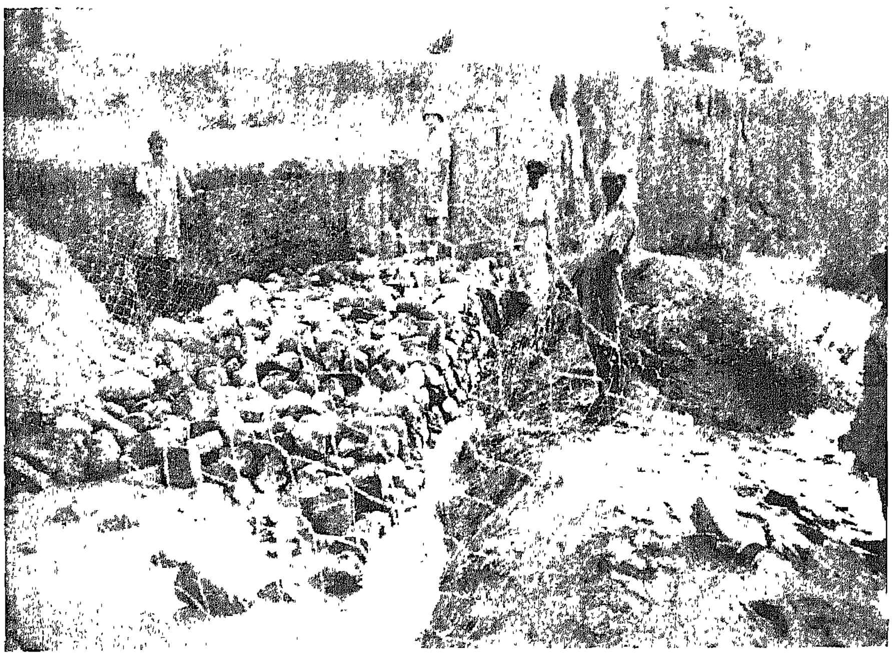


PLATE 10 (i).

Rock rubble piled into a crate or bolster of wire. When built to a suitable height the wire is pulled tight and strapped across the top to form a tight bolster. This shows its use as a spur to protect an eroding bank but the same type of structure serves as a check-dam.—paras 6.26 and 10.18.

PLATE 10 (ii).

Gully plugging in the upper reaches of Bachoi Cho immediately below the main Siwalik watershed near Baukhandi; silt has been caught by stone check dam and planted with *Nara* grass and *Ipomaea*; kahi is spreading naturally. Only the top of the wingwall is now visible, the rest of the check dam being buried in the silt.—para 6.21.

should be attempted unless suitable stone, brick, timber, or brushwood is to be had near the spot.

6. 24. *Brushwood Check-dams.*—The use of brushwood is justified if plenty posts can be driven, against which the brushwood can be warped and packed down. A row of posts should be driven at an angle so that their tops slope upstream and the brushwood is packed against their upstream face. The brushwood packing should be roped or wired and weighed down with large stones. The posts used should be of tree species such as *Jernea grandis, sissoo,* and *Ficus* which will strike root, and these should be set up in holes driven by a crow-bar if solid bed rock is exposed. The use of wattling for hurdles and buried cables of twigs or reeds is explained diagrammatically in Figures 21 to 24.

6. 25. *Wooden Crates.*—Where rough timber such as sawmill scrap or side-slabs from forest conversion are available this can be used to build wooden frames into which rock and boulders are packed. The opportunities for this type of work will however be few. In using these the same essential point must be attended to as in the case of loose stone, namely that the frame should be well bedded down in the bed of the stream so that it cannot readily be undercut, and wing walls must be sufficiently firm and high to prevent the flood from side-cutting and isolating the structure. (See Plate 13 i).

6. 26. *Loose Rock or Wire-bound Rock.*—Where rough stone is used for dry masonry or rock-fill dams it is essential to have the foundation dug out to a minimum of 18" below the stream-bed level, and the lower courses should be of long stones laid with their long sides parallel to the direction of the torrent. The downstream face must be well set back downstream as a toe to reduce the danger of the whole being overturned by the flood. Such check-dams do not attempt to pond back water, so the complete stopping of seepage is not important, but the stability of the structure is vital. It is essential that the middle of the lip should be concave upstream to an extent of 1 in 6, so that the force of the flood will tend to lock the whole tighter in position (Figure 25). Cupping in the horizontal plane must also be well marked with the middle of the cup at least 18" below the height of the wing walls. (Fig. 26). Where wire binding is to be used hog-wire of 10" mesh and thick guage will last many years; the wire should be stretched and moulded to the bed, then filled up with packed rocks, and the loose ends of wire bound tight over the top and sides. (Plate 10 i).

6. 27. In the Pabbi many of the small stone bunds, built as long ago as 1880, can still be found more or less intact, also some

Fig. 21. TYPES OF BRUSH-WOOD CHECK-DAM.

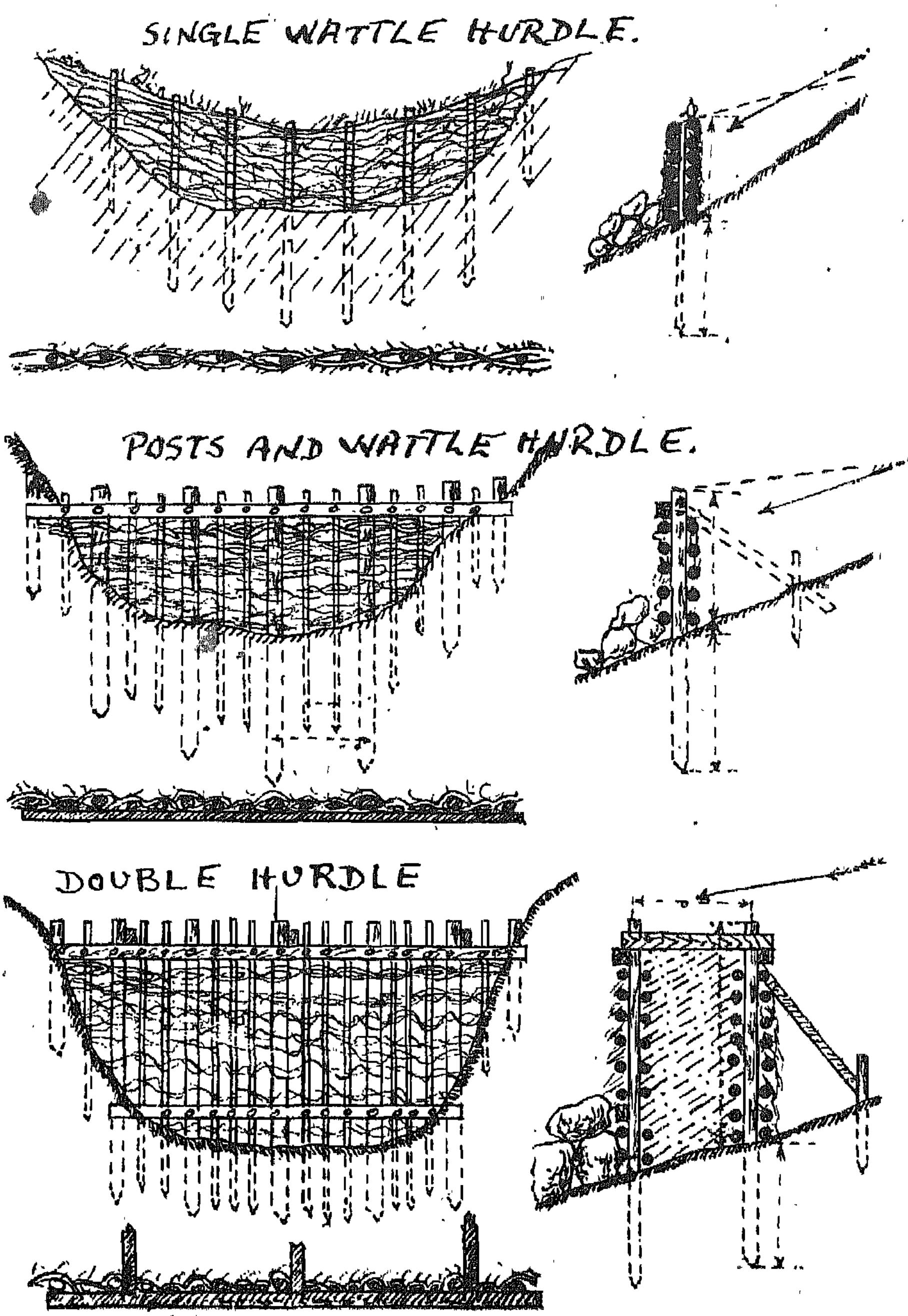
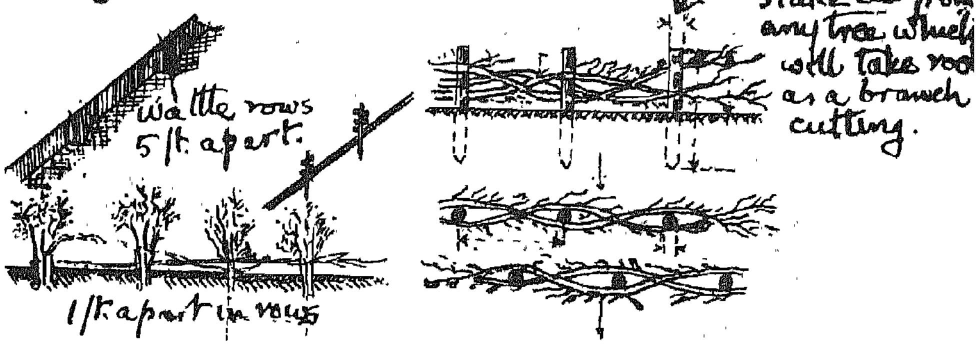
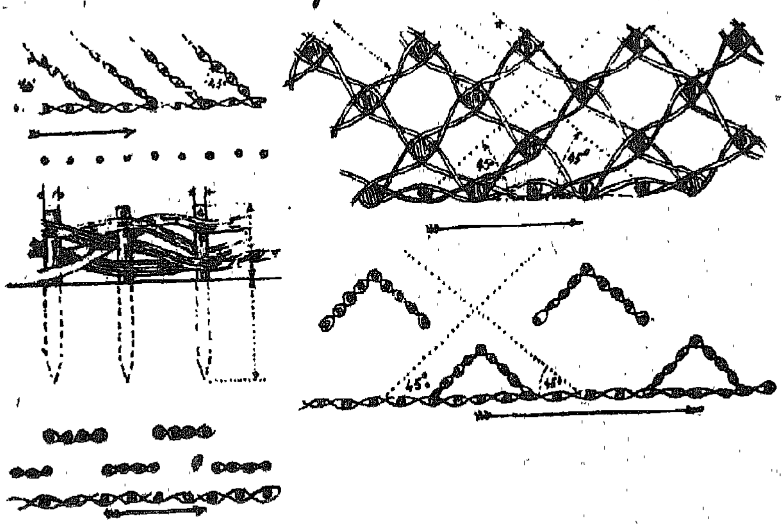


Fig. 22. CONTOUR WATTLING.

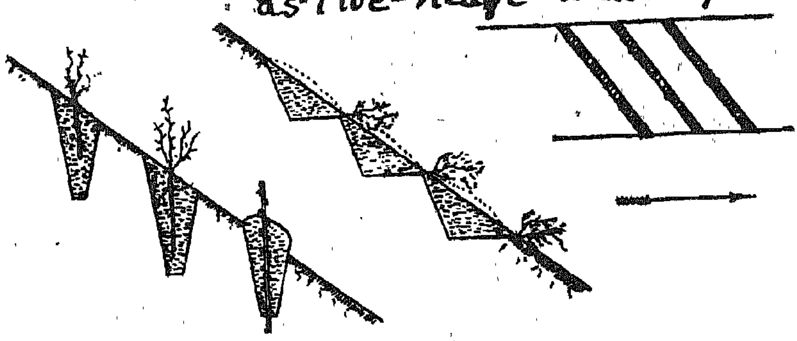


For revetting railway and road banks and important land-slips.

Criss-cross pattern of wattling.



Contour planting for subsequent use as live-hedge wattling.



WATTLING.

Fig. 23. AFFORESTATION OF LAND-SLIPS.

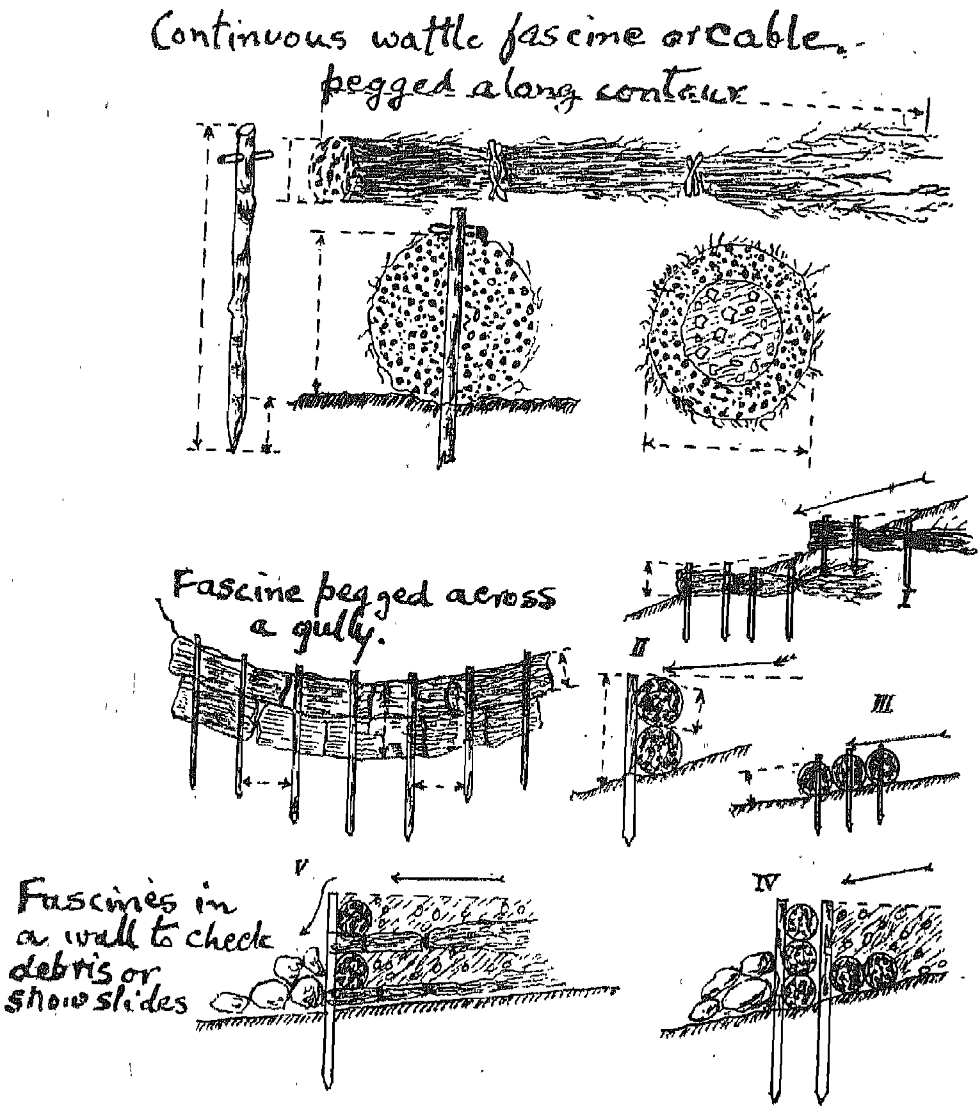


Fig. 24. CONTOUR WATTLING.

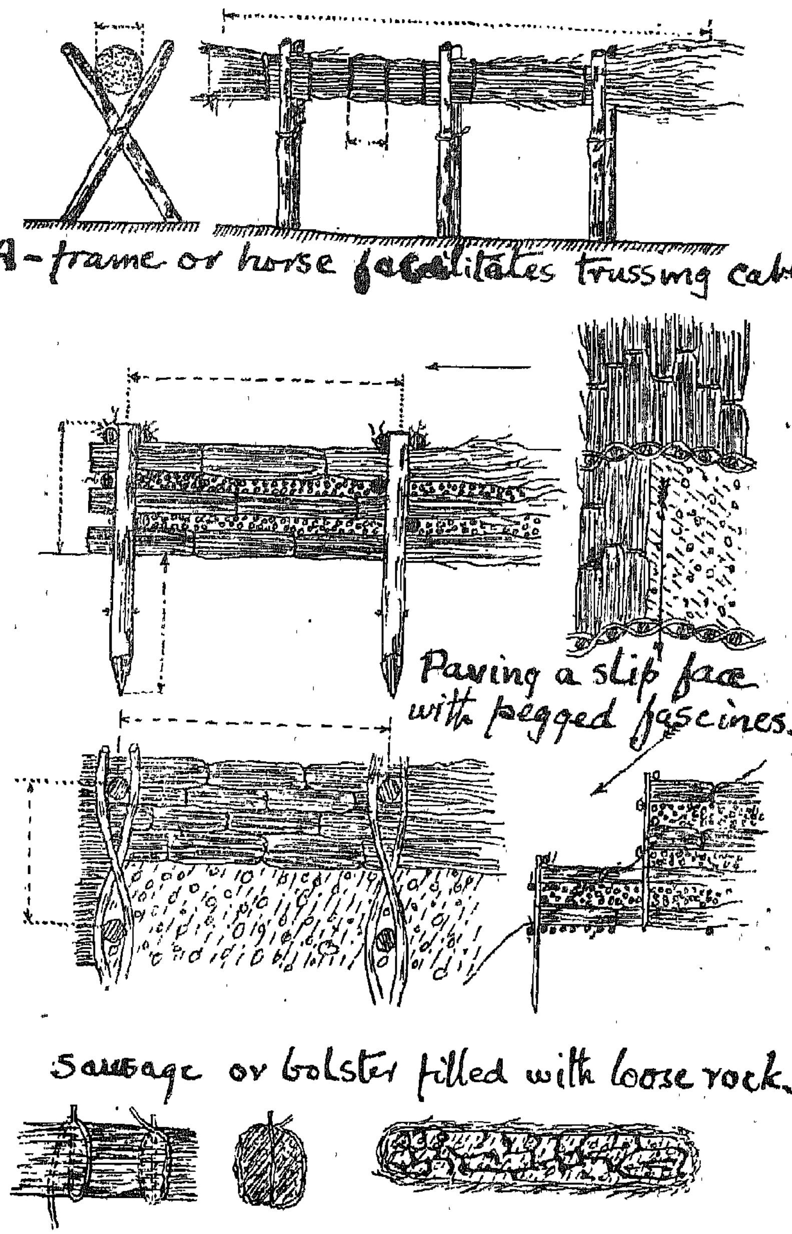
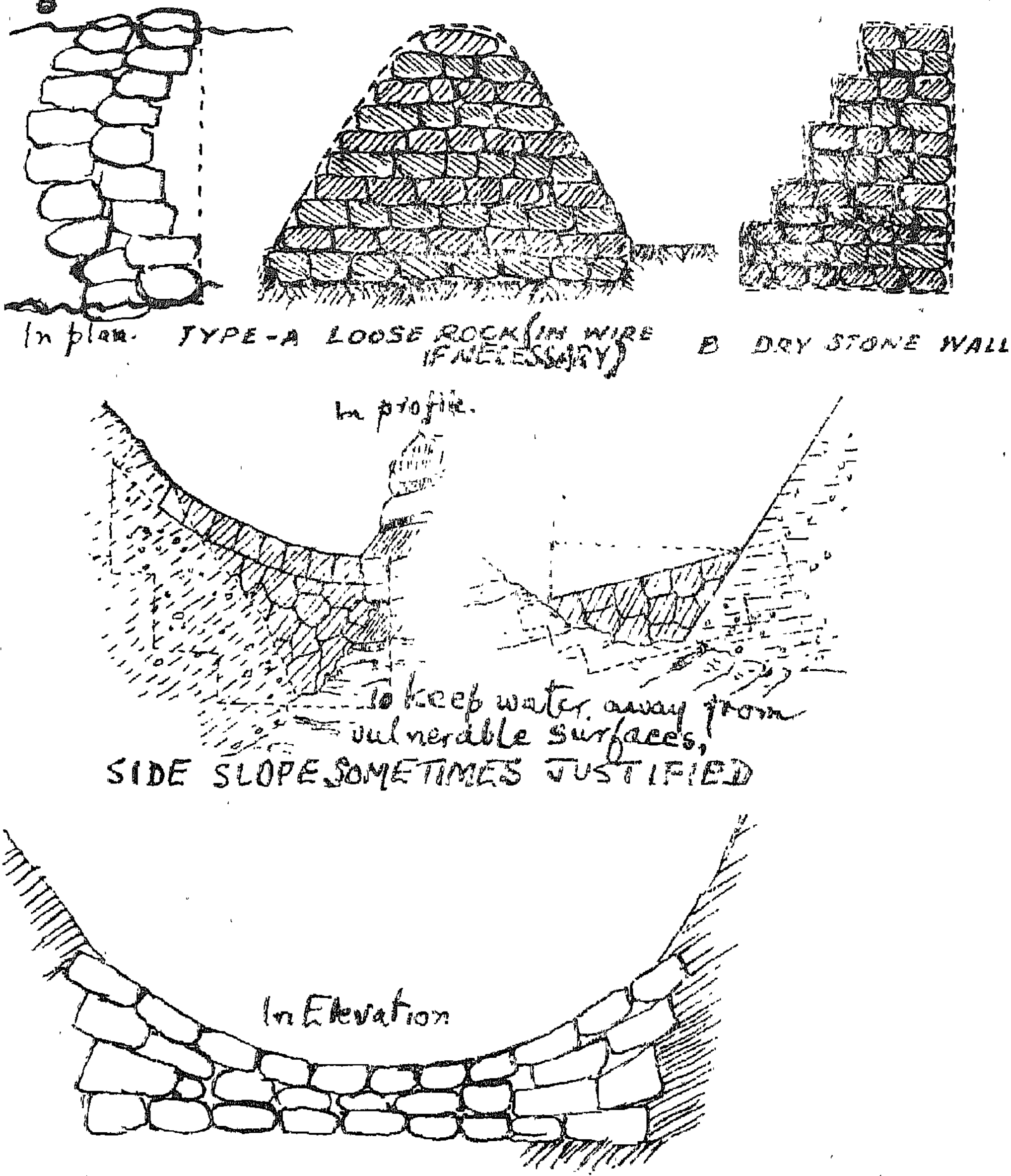


Fig 25. DRY STONE CHECK-DAMS



PROFILE FOR TYPES A AND B WITH OR WITHOUT WIRE BINDING.

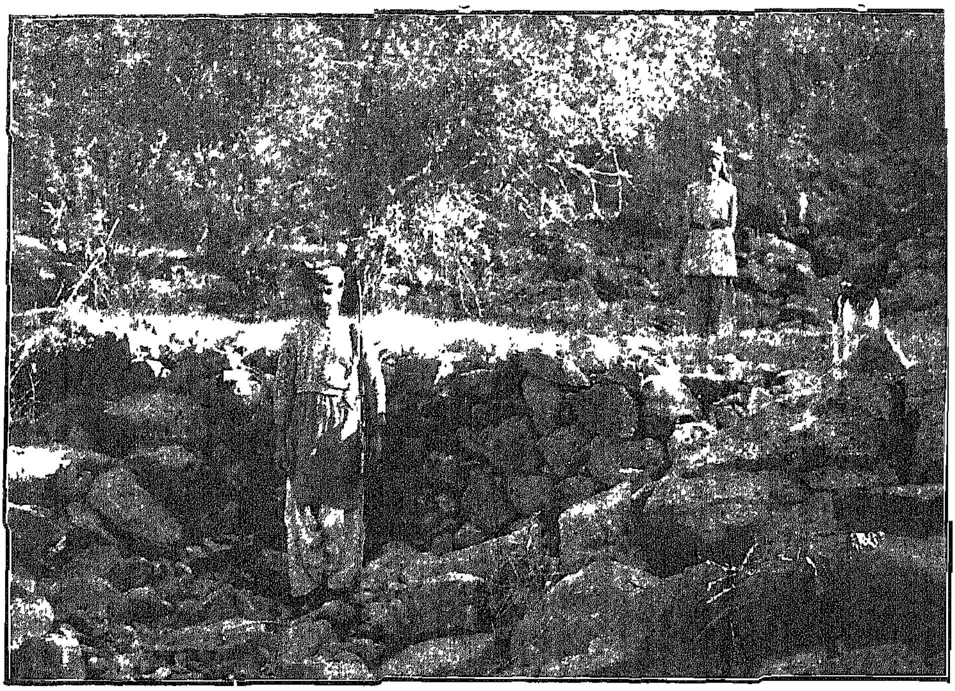


PLATE 12 (i).

Dry rubble checkdam built in Kalachitta in 1905 which has survived intact because well buttressed; Para 6.28; top too flat.—Para 6.31.

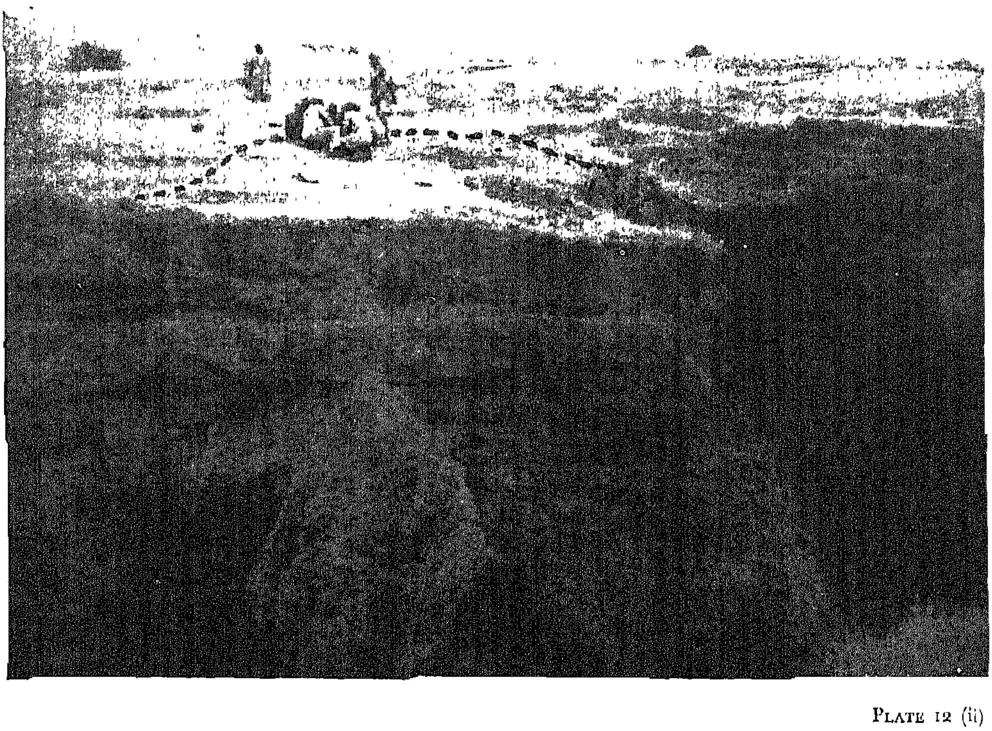


PLATE 12 (ii)

Explosives for gully-plugging. Laying an explosive charge of 25 lbs amonol at the bottom of a 10 ft. bore hole m [illegible] The dotted line shows where the cliff broke away as a result of the explosion.—Para 7.21

in the Choha block of the Kalachitta hills south of Campbellpur, which had been built in 1906-8. The completion of a 5-year working plan prescription of check-dams in all the branches of the Bachoi-Maili cho during 1939-46 has given us further valuable experience. A total of 4500 acres has been provided with check dams at a cost of Rs. 43,000 or Rs. 10 an acre against an original estimate of Rs. 8 per acre. It is largely owing to this lavish use of check-dams that the almost complete canalisation of both Bachoi and Maili chos has proved to be feasible in 4 years work on the plains below.

6.. 28. *Failures.*—A study of such old bunds gives us some valuable pointers. Most of those that have collapsed have been undermined by the water working round either flank and resuming its cutting action at one or other side. Those that have stood up best have been well buttressed on each flank against some solid object such as a large boulder or an underlying sill of rock, but such things are not always available. In their absence the best precaution against undermining is to have the sill hollowed to a deep concave curve, so that even with an appreciable flow of water, the main force of the torrent will be confined to the channel in which it is meant to flow. (Fig. 26).

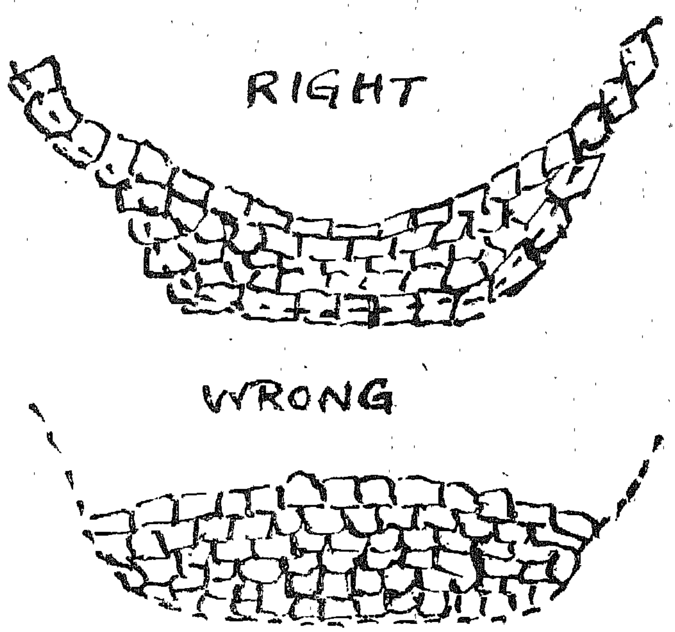


Fig. 26 PROFILE OF CHECK-DAM.

The importance of this point in the construction was not appreciated by the early workers, with the result that a good deal of their labour has not stood the test of time. Examples illustrating success and failure are shown in *Plates* 11 *and* 12.

6. 29. *Spacing.*—Another point of vital importance is the vertical spacing of bunds in a stream bed. Too few bunds are pactically useless in preventing the further scouring out of a V-shaped torrent bed, because the stream regains impetus in the intervals and continues to cut down deeper. Bunds must be only so far apart that the top of each is practically on a level with the base of the one upstream from it. (Figure 27).

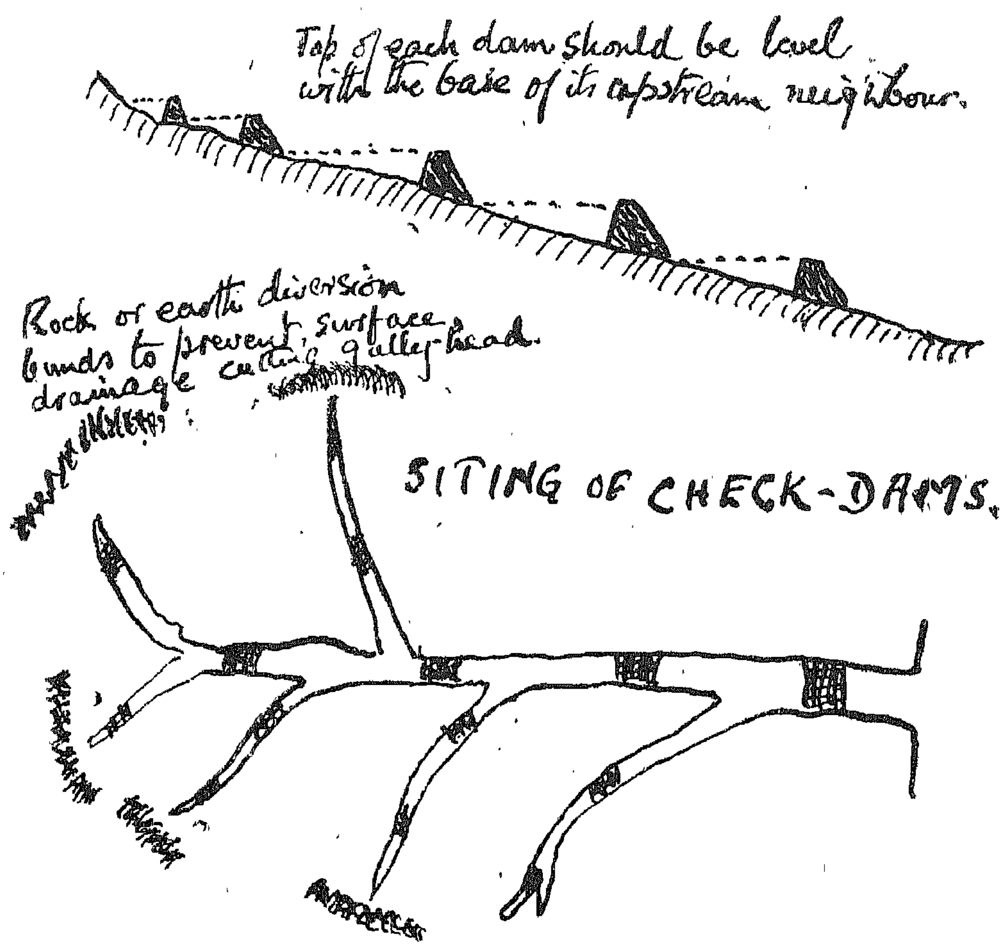


FIGURE 27.

This ensures that each bund makes a flat terrace behind it, in which the water moves down without regaining much velocity. If this principle in laying out a torrent control project is ignored and the bunds are spaced much wider apart than this rule allows, it will inevitably prove a false economy, for the bed will be dug down deeper until eventually the bunds will be either undermined or side-tracked. An example of imminent undermining caused by this very reason is shown in plate 12.

6. 30. This question of spacing is so important that no project of bund-building should be taken up unless there is some reasonable prospect of being able to complete the whole of a given stream channel or at least the main section of its length where torrent action is evident. Isolated bunds put down here and there without forming part of a definitely planned and comprehensive project are just so much waste of money, unless they can be justified as a local trial of conditions and materials on a small scale and as a preliminary test leading to further work. The close observance of this spacing rule will naturally make the treatment of steep *nalas* very expensive, because the steeper the gradient, the closer must be the bunds to each other. Stream gradients of anything up to a 1 in 8 fall lend themselves to this type of control and bunds can usually be built at a reasonable cost. Anything steeper than this entails a vast number of bunds, and it is suggested that, unless the torrent in question is of particularly vital importance, such as in the protection of important buildings or engineering projects, its flood control can be better handled by concentrating upon plant cover conservation in its catchment area.

6. 31. *Stability of Check-dams.*—Failure is commonly in 3 ways. Firstly by the stream cutting around one or the other abutment and so leaving the whole structure isolated. Secondly by under-cutting at the downstream toe, thus leading to the whole structure overturning in a downstream direction. Thirdly by direct structural failure due to internal stresses and the removal of key stones by the flood.

The first of these can best be met by attention to wing walls as already mentioned. The other two can best be met by the skill of the mason in fitting dry stone blocks into a close fit. Hence the need for the structure being concave upstream so that they bind as in an arch under pressure. Where persistent breaching occurs or where stability is of special importance wire cribs should be used to hold the stones together, either at the toe or for the entire structure. (Figure 25 and Plate 10 i.)

6. 32. *Earth dams.*—In the strict sense of our definition of "check-dam", *earth alone cannot be used* unless to pond back the whole flow in small branch *nalas*. Attempts to use earth alone for check-dams in the past, chiefly in the Pabbi Reclamation Area in 1921-28, proved very expensive in upkeep as they were made barely strongly enough owing to the expense of hand labour, and usually required a pipe or well-head syphon or paved spill-way to prevent breaching. Now that earth-moving machinery can be used for this work, it will probably pay to make them big enough to stop overflow entirely for 2 or 3 monsoons, after which the rate of silting and of filling can indicate whether a *pukka* outlet or spillway is to be provided or not. Some form of scour-proof escape to lead off heavy floods is absolutely essential in every case.

6. 33. For earth bunds, it is often feasible to make a core wall of impervious material such as clay or concrete. The foundation must in any case be taken down if possible to an impervious layer which will give some assurance against heavy seepage; where there is no rock but a considerable depth of coarse sand in the bed, reliance must be placed on beating in a core of clay to a depth of say 3 ft. below the stream bed level and carrying this up as a core wall to 2|3rds the total height of the finished dam. The core wall is then buried with earth, which should be well rammed in thin layers of not more than 4" depth at one time, to the full width of the base to allow slope of 1 in 2 upstream and 1 in 2½ down-stream.

6. 34. The use of bamboo instead of metal rods as reinforcement in the concrete (used either for such core walls or for entire concrete dams) is recommended for extensive trial, and careful records should be kept over a series of years of its reliability. The bamboo used should be well selected solid *bans* (*Dendrocalamus strictus*) dry, straight and cut to suitable lengths of 8-12 ft. and entirely free of borer, to test which some samples should be split open before acceptance. Surface and ends should be well coated with creosote and allowed to dry before being bedded into the cement. The spacing should be such that each bamboo is isolated from its neighbours by the concrete mix. The mixture ratio of cement to sand and broken stone or pebbles should be according to departmental standing orders.

6. 35. *Spillways for Earth dams, Check-dams and Field Bunds.* Earth is the obvious material for building dams which are intended to catch either water or soil, particularly when no good rock is available. The provision of an ample spillway of resistant material is however absolutely essential, for no matter

FIG.25A.-TYPES OF MASONRY SILL.

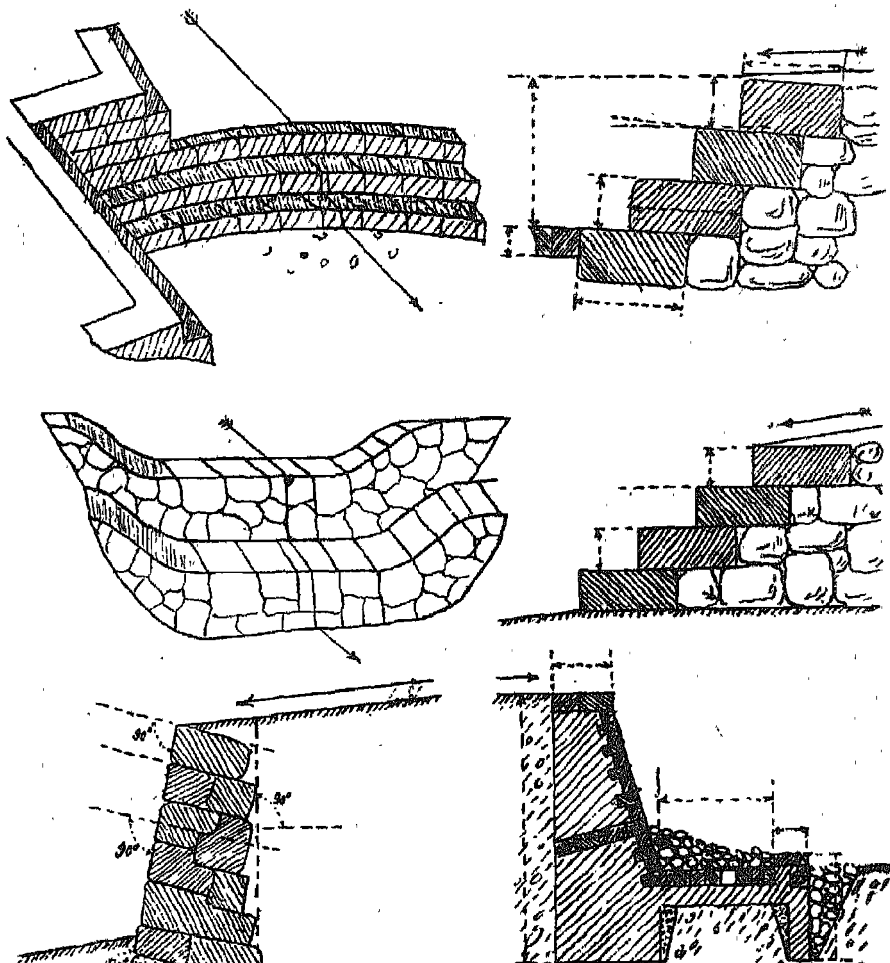
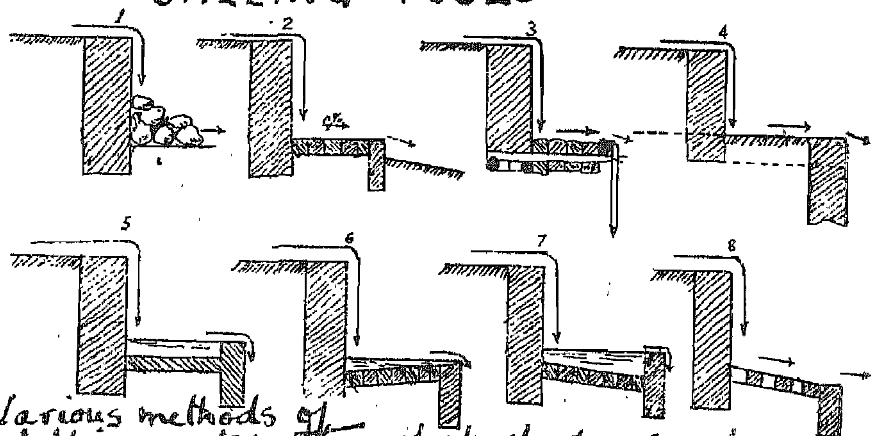
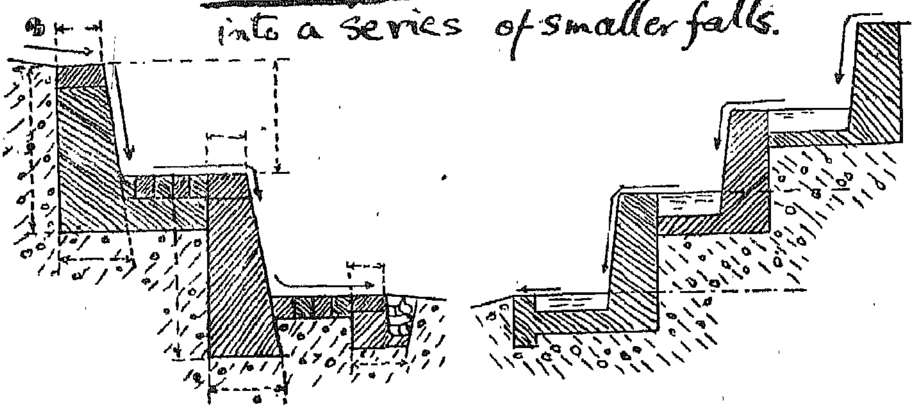


FIG. 25B.- STILLING POOLS



Various methods of stopping undercutting of check-dams and spillways.

Breaking a high fall into a series of smaller falls.



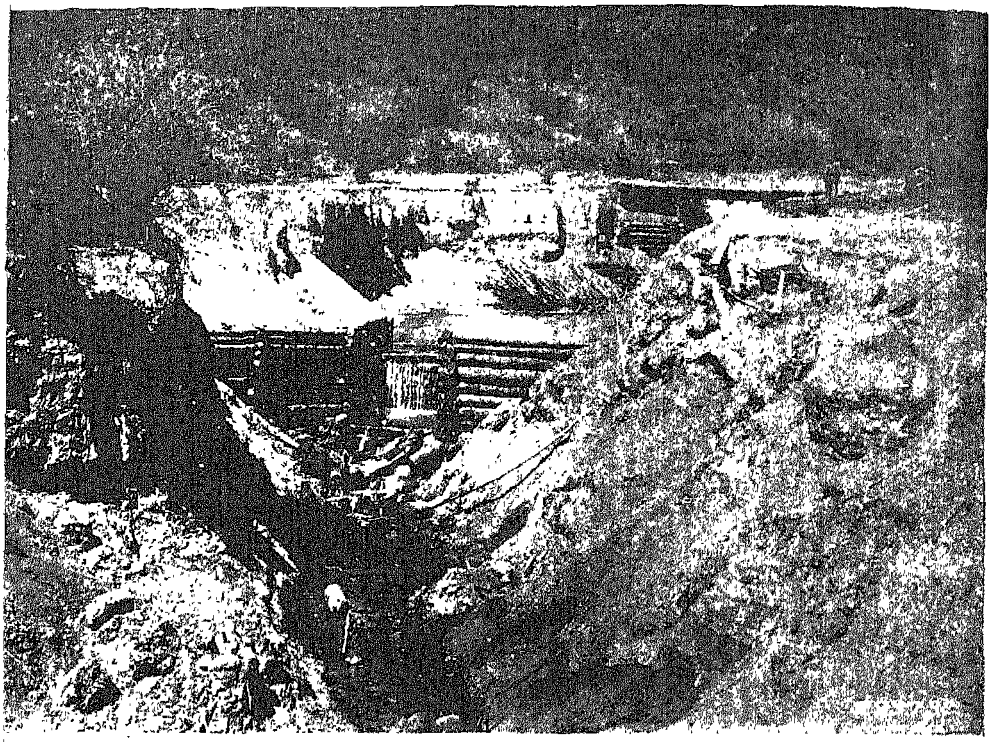


PLATE 13. (i)
ntrol work with *Pinus pond. rosa* logs in one of the channel valleys of southern Utah. The problem of control here is very r to many places in Kangra where alluvial benches along a valley bottom are desiccated by deep gullies. The latter upset natural drainage levels.—Para 6.25.

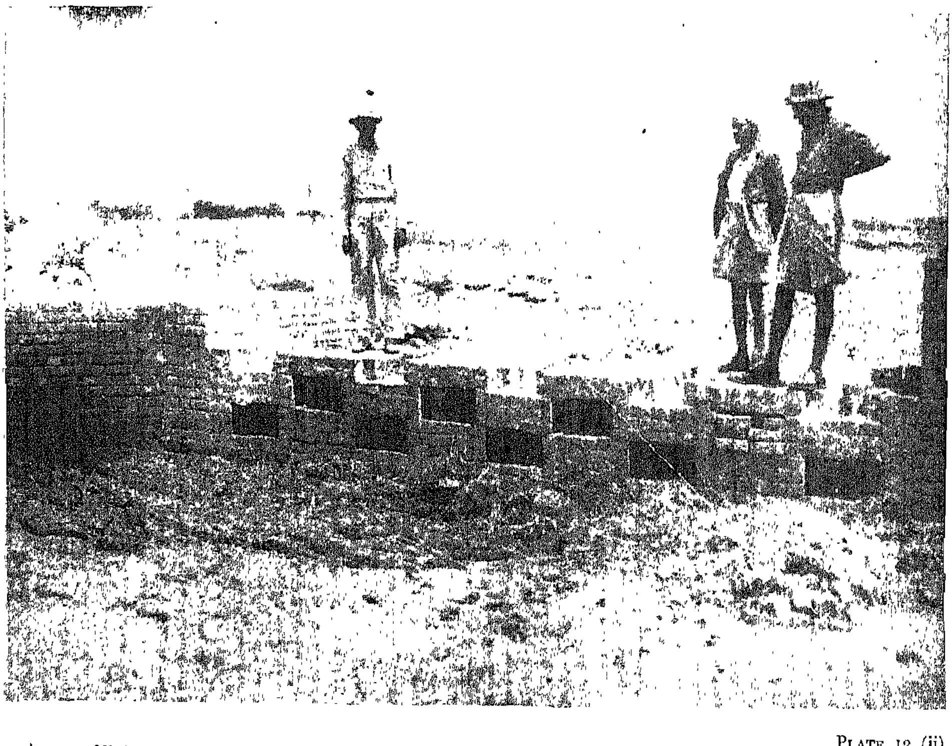


PLATE 13 (ii)
A type of light brick sill with a series of apertures which can be blocked up gradually & so regulate the pace at ich the reservoir area becomes silted up. Top aperture on right has been fitted with bricks to show how apertures closed. [illegible]m Salt Range. Compare Figure 10A.

how big the earth bund is made in the first instance, it is only a matter of time before the collected water flows over the lowest point, and once a breach has been formed, nothing can prevent the rest of an earth dam from being washed away. Practically every known failure of earth dams is due to failure to provide a free passage to the super-flood, when all previous records of stream flow are surpassed.

6. 36. Previous zamindari practice in the Punjab has been to provide a solid wall with its plinth below the base of the earth dam, and the wing walls carried up into the earthwork, with earth packed around the wing walls. This type of outlet is expensive and is not in all cases essential. Figures 25A and B. The spillway of earth bunds with a heavy discharge should be of concrete or brick in cement plaster, but for catchments of less than 10 cusecs discharge, dry stone pitching should be sufficient. It should not usually be necessary to carry this concrete or brick downwards as a wall below the base level of the bund, provided the masonry is laid down as a skin on top of the shaped spillway and reaching downwards on both upstream and downward slopes to a distance which will prevent serious cutting of the earth in the bund and at its toe.

6. 37. The Missouri Spillway featured in the April 1945 issue of the *Central Board of Irrigation Journal* and reproduced in figure 28 is a useful type of concrete spillway to insert on the lip of any earthen or rubble dam where a dry stone spillway would not be strong enough to carry a considerable rush of overflow water. Before laying the masonry the bed of the spillway over the made dam is prepared. The soil is smoothly packed to give the desired shape, then the masonry or concrete or reinforced concrete is laid down on this. The reinforcement (iron rods or solid dry bamboos) is laid in the required position with a skin of cement 2" thick above and below it. The spillway in its finished condition consists of an unbroken sheet of cement but its chief component parts are (1) wing walls lapping the upstream face of the aperture and extending well outwards and upwards over both shoulders of earthwork, (2) the main water channel broad enough and deep enough to carry the expected overflow, (3) a stilling pool formed at the bottom of this channel by rounding off the downward slope and inserting a cross-bar of cement. The base of this apron should be at a level well below that of the stream bed of the main drain.

Other useful patterns are shown in Figures 29 and 30 for a sloped open flume and an enclosed conduit or culvert, both V. S. Soil Conservation Service patterns, and Figure 30A and Plate 13 ii which illustrate a soil-sowing bund developed in Jhelum and suitable for wide shallow depressions which can be silted up gradually under control.

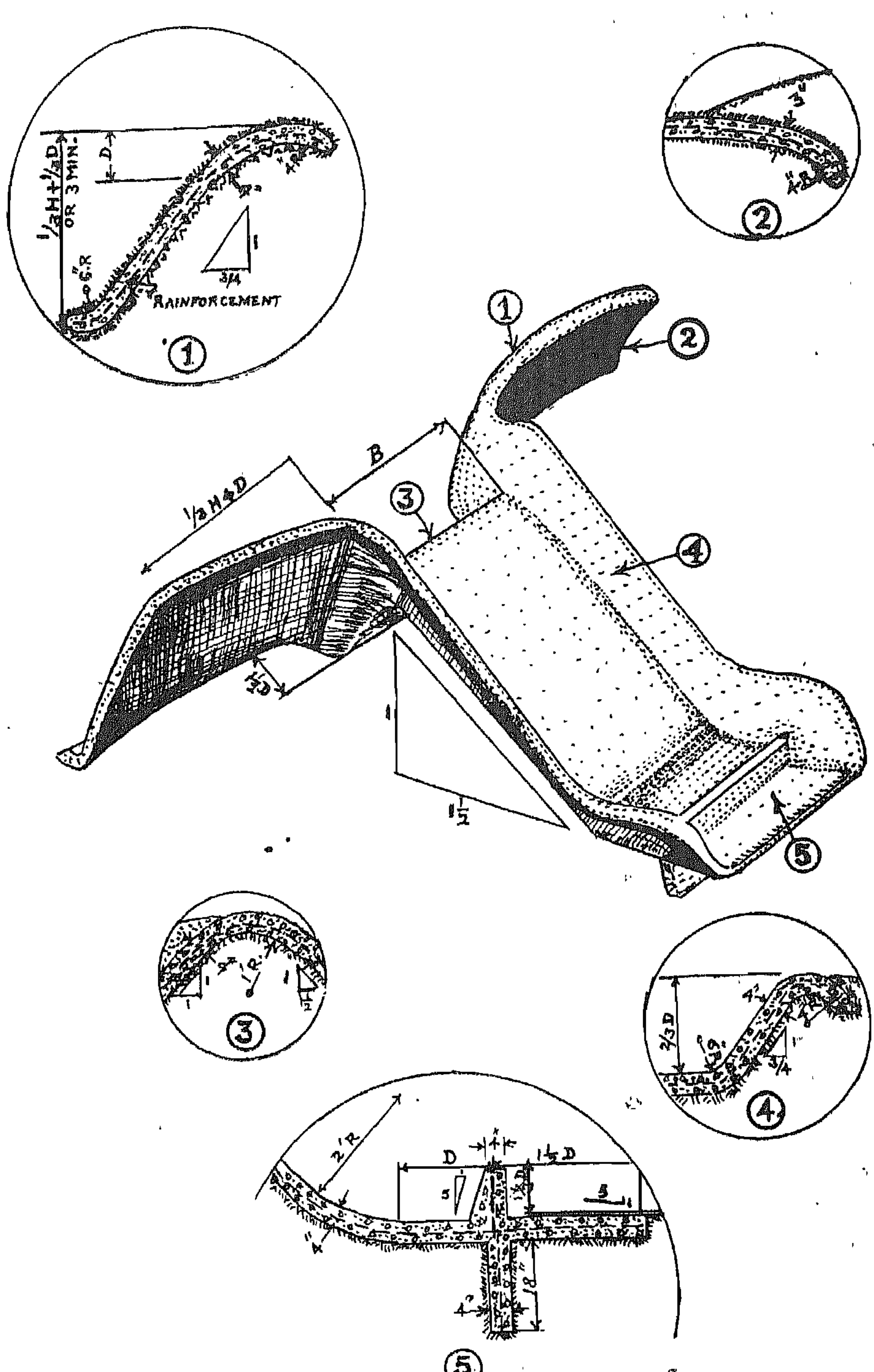


FIGURE 28 MISSOURIE SPILLWAY.

Perspective Drawing showing complete Missourie Dam as it would be if removed from the ground,

Courtesy of Central Board of Irrigation, Journal, April 1945, Page 71.

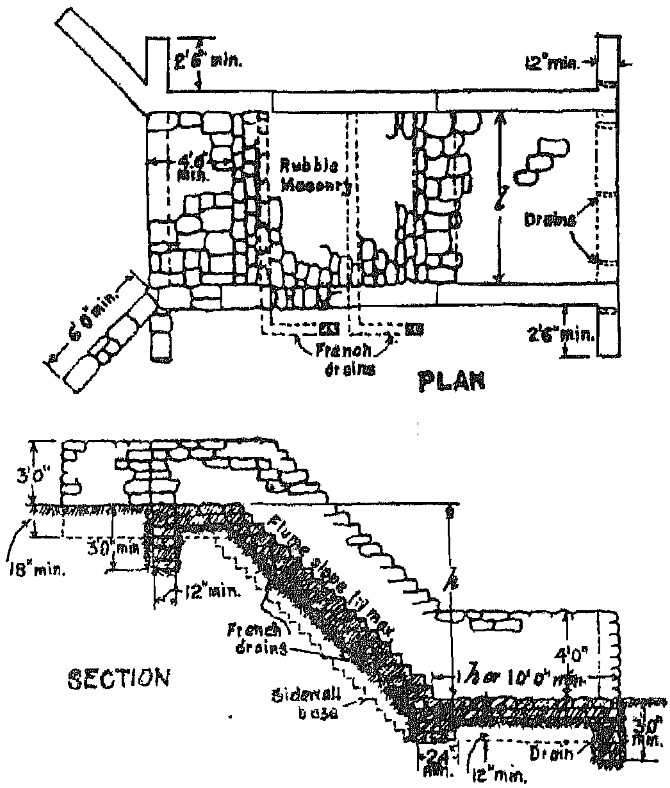


FIGURE 29
Masonry Head Flume. (*Soil Conservation Service, U. S. A.*) Para 6.37.

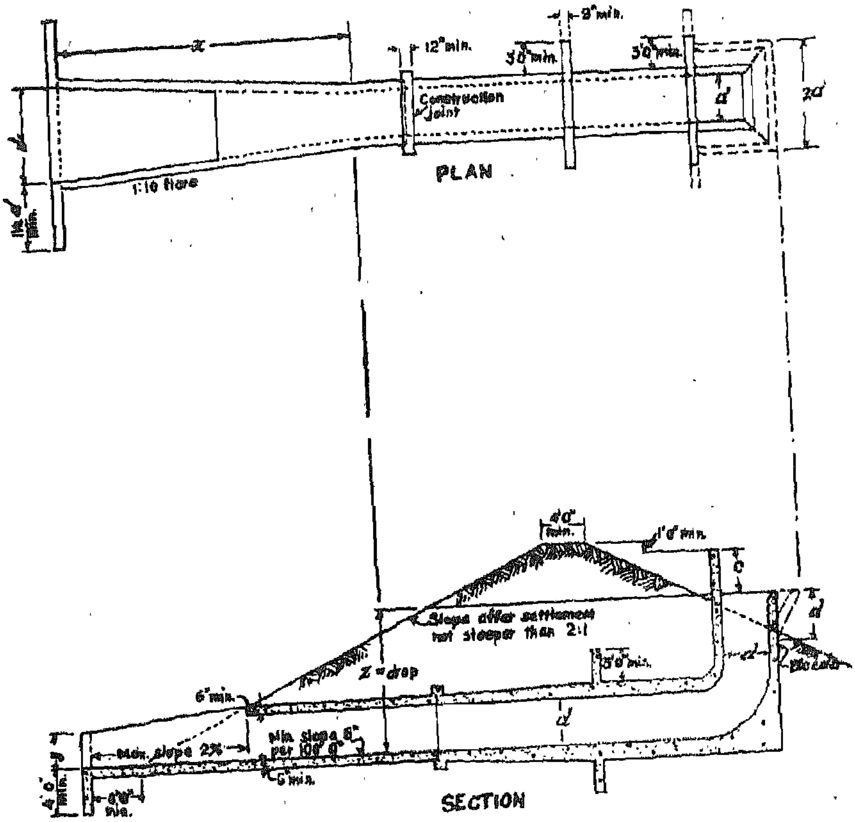


FIGURE 30

Drop-inlet Soil-saving dam with square conduit. The dimensions c. w. x. and y vary according to size of conduit used. Para. 6.37. (*Soil Conservation Service, U. S. A.*)

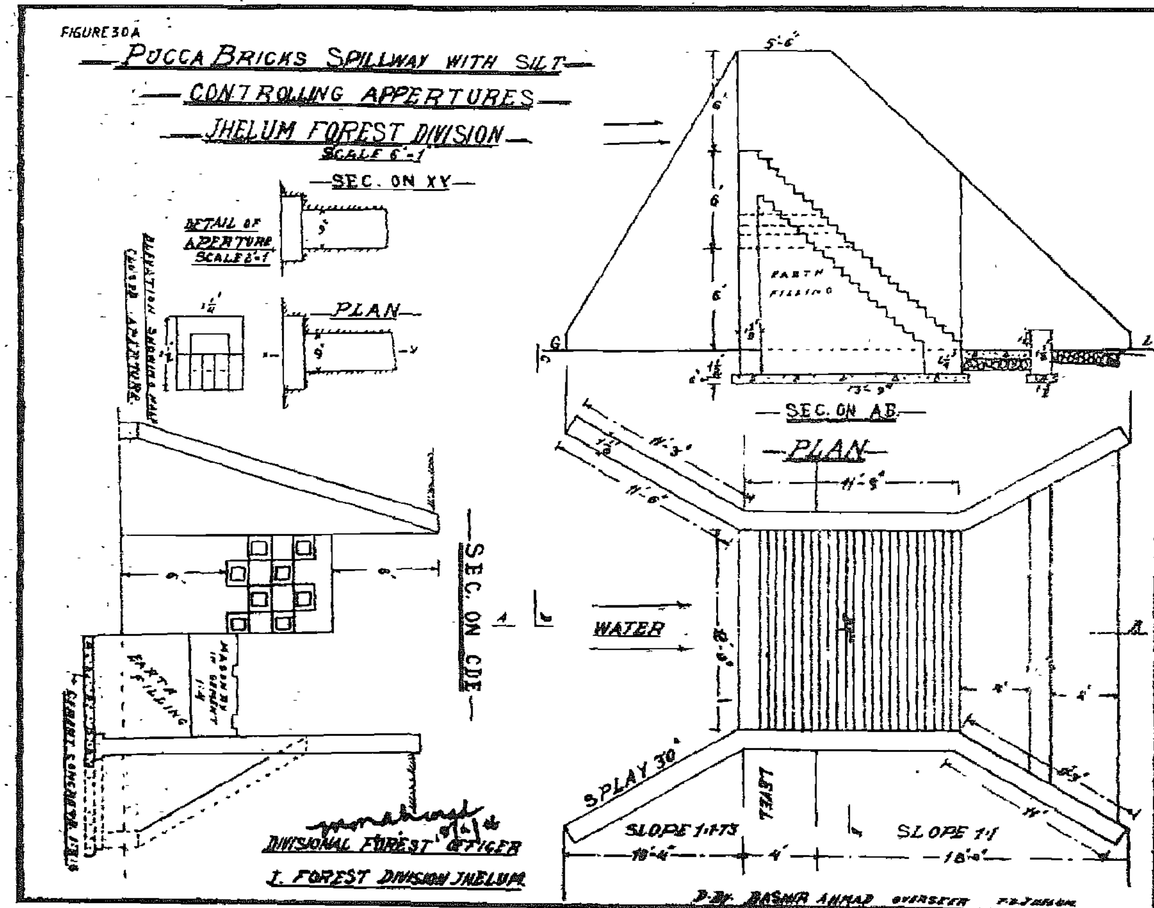


FIGURE 30A
PUCCA BRICKS SPILLWAY WITH SILT
CONTROLLING APPERTURES
JHELUM FOREST DIVISION
SCALE 6'-1
SEC. ON XY
DETAIL OF APERTURE SCALE 6'-1
PLAN
ELEVATION SHOWING HALF CLOSED APERTURE.
SEC. ON CDE
MASONRY IN CEMENT 1:4
EARTH FILLING
CEMENT CONCRETE 1:3:6
DIVISIONAL FOREST OFFICER
I. FOREST DIVISION JHELUM
SEC. ON AB
EARTH FILLING
PLAN
WATER
SPLAY 30°
LEVEL
SLOPE 1:1.73
SLOPE 1:1
D. By. BASHIR AHMAD OVERSEER

Chapter VII.

LAND RECLAMATION WITH MECHANISED EQUIPMENT.

7. 1. During the winter and spring of 1940-41 Britain cleared and drained as much swamp land in 7 months as Italy did in 13 years' work in the Pontine Marshes. Before the war this Italian project was considered a tremendous achievement but it has been dwarfed by the British application of soil-moving machinery to the reclamation of their own hill waste land. Little has been heard about this marvellous British effort as it was done as part of the contribution to war work. It does however point to the enormous value of these new weapons which are now available to assist us in our attack on the waste land problem.

7. 2. The first record of mechanised equipment being used for soil conservation work in India was by G. W. D. Breadon, district engineer of Gurdaspur, who employed road graders for terracing the very deeply ravined lands of Shakargarh in 1936. In a privately printed paper reporting the success of this experiment he stated "In my humble opinion soil conservation ought to take precedence over any scheme of irrigation expansion." The next record of land reclamation of this sort is by M. P. Fletcher on the private farm of H. H. the Maharaja of Jodhpur in a paper presented at the Crops and Soils Wing of the Imperial Council of Agricultural Research in November, 1943.

7. 3. In assessing the value of land reclamation it is customary to take the present value of the land and compare this with its improved value to the individual who owns it, but all land has a value to the nation apart from its value to the individual who uses it. Expenditure considerably above its improved rental value may be fully justified if it is to guarantee this land as a permanent instead of a wasting asset to the community, particularly if the only alternative is its complete loss through continued misuse or erosion.

The reclamation of our 2 million acres of ravined lands in the Punjab is a case in point; in their present condition they are not only unproductive, they are a menace through the flood damage which they cause elsewhere; reclaimed, they will cease to be a menace and will be producing more food for the nation.

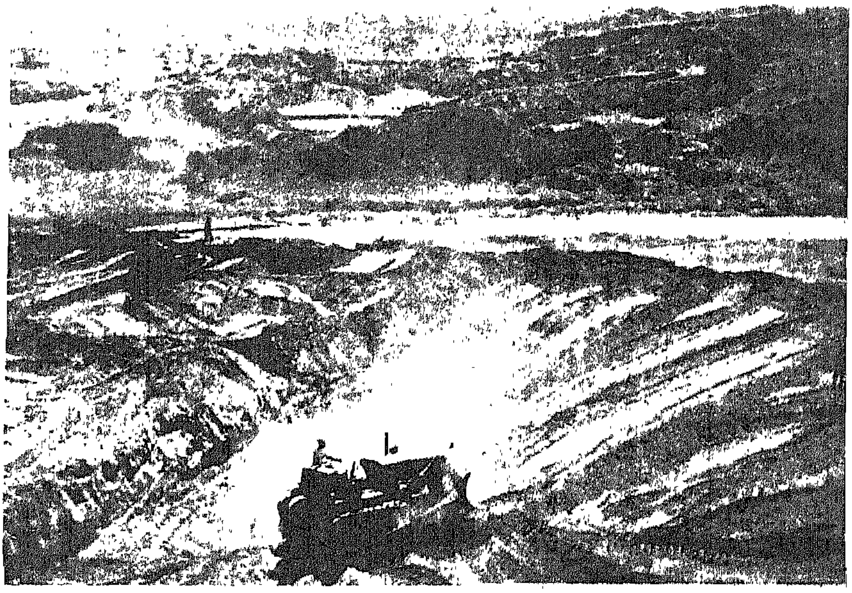


PLATE 14. (i)

Building watts by bulldozer in Kariala village at mile 97 between Jhelum & Kharian. The torrent banks will be planted up and kept under a shelter-belt. Note very small area of existing fields amongst gullies on far side of the torrent bed.—Para 7.5

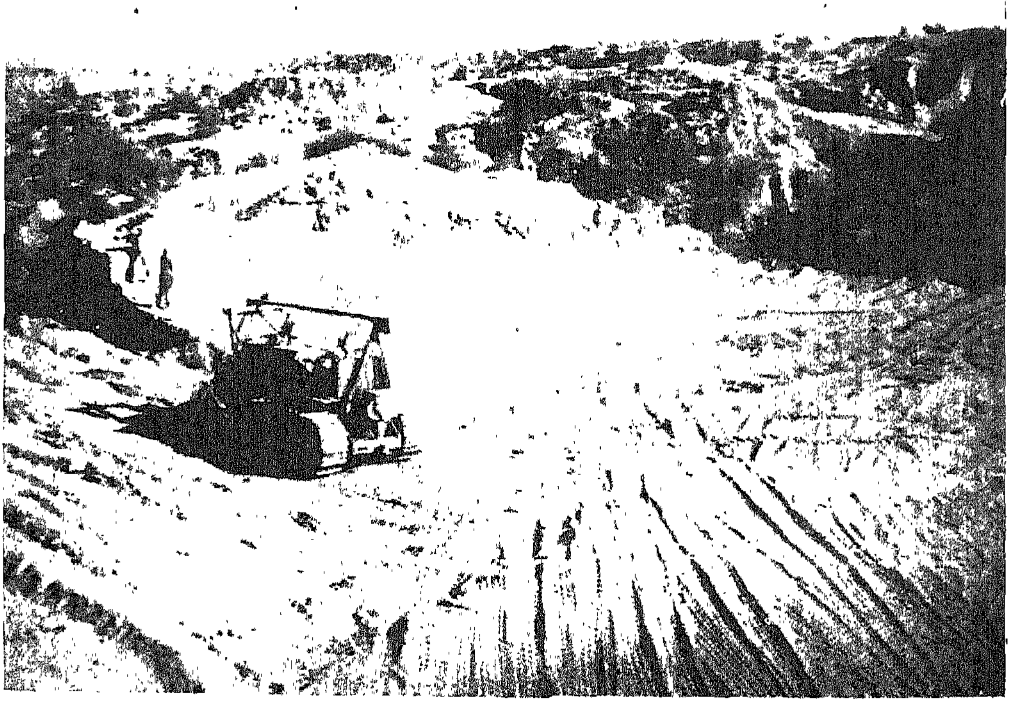


PLATE 14. (ii)

A bulldozer completing the filling of a hollow in a partially levelled hill top between two ravines in the Pabbi hills. Rough country behind is typical of the Pabbi where passive protection over many years has failed to stop erosion.

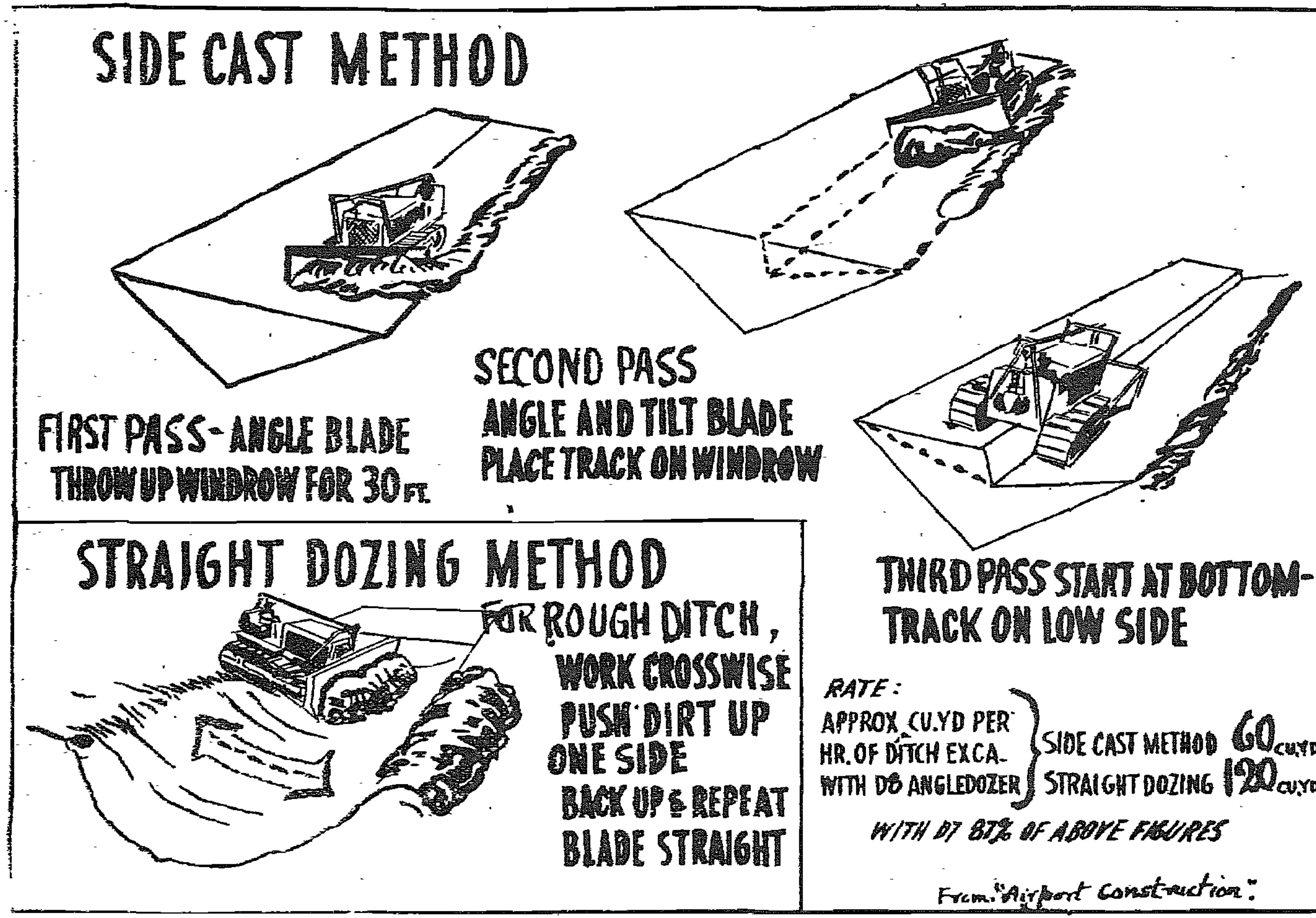
7. 4. In the Punjab many thousands of acres of good land are being lost each year through the failure of the individual cultivator to protect his fields against gullying. In Jhelum district alone 50,000 acres of good land have passed out of cultivation in a period of 35 years as a result of gullying, sheet erosion, and torrent action.

In applying the army's dearly bought experience of building aerodromes and mountain roads to the reclamation of the Punjab soil, there are four distinct types of job to be undertaken, corresponding roughly to the average slopes and the extent to which gullies and deep ravines have already been cut by rain and torrents.

7. 5. *Types of Reclamation Work.*—First there is the gently rolling upland type where the light sandy soils are being dispersed by sheet-wash so that long unbroken slopes of land now ploughed are gradually becoming sandier through the separation and removal of the finer silt particles. This is common all along the base of the Himalayas, also in the upland plateaux of Gujrat, Rawalpindi, Jhelum and Attock and in the neighbourhood of the main river banks. The remedy is in extensive contour ridging on the lines already done with hand labour in Bijapur, Bombay, but in our case could be more efficiently done with an agricultural tractor-plough or terracer as well as the bulldozer. It is of course being done by individual cultivators using the bullock-drawn *karah* or scoop, but there are such vast areas needing attention that something more than man and bullock power is needed, even to overtake maintenance and repair of breaches.

7. 6. Secondly, there are the deeply ravined lands, familiar to road users around Gujar Khan and all too common wherever slopes are steep. Here the heaviest type of bull-dozer or angle-dozer is the correct weapon, for it can straddle and flatten even the steepest ridges and pinnacles, pushing them down into terraces which can be cultivated once more. A demonstration of what these machines can do has been prepared by an army unit, No. 6 Group Indian Engineers, in the Pabbi Hills between Kharian and Jhelum as part of the training of their drivers and at no cost to the owners of the land. This experiment has given us a clue as to what this type of reclamation will cost. That it is feasible mechanically there is no doubt, but at a price. It will be for government to decide how far they are justified in allocating large sums of money to rescue land which has not only passed beyond the use of the owner but is a menace to the countryside in initiating disastrous floods. We are offering to make a silk purse out of a sow's ear, as the old saying goes, for this land is

FIG. 31. ANGLEDOZER APPLICATION - DITCH CONSTRUCTION



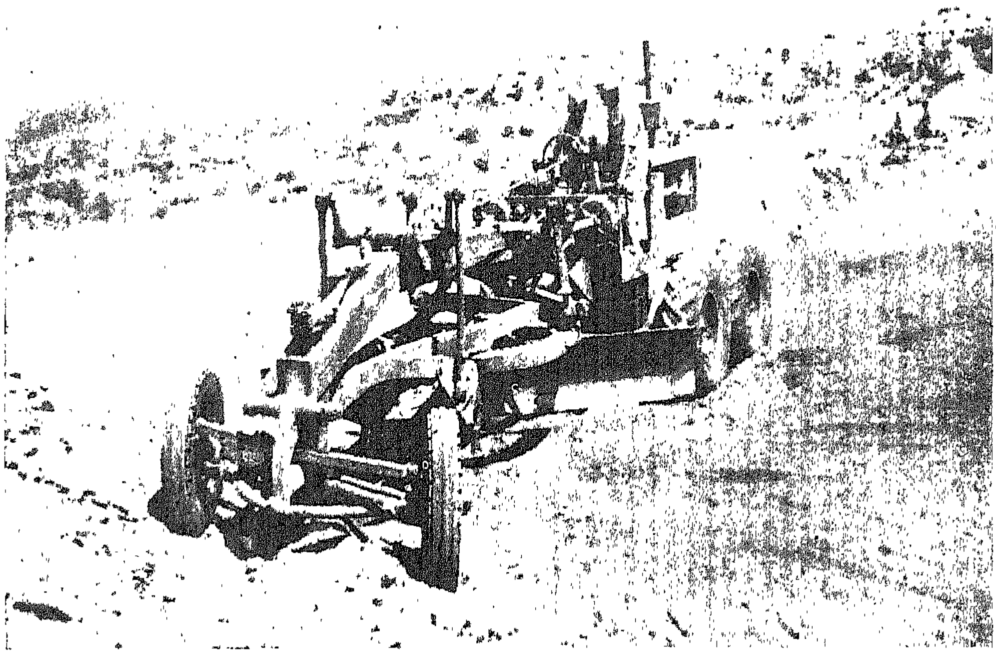


PLATE 15 (i)

A motor-grader suitable for finishing off the levelling of rough ground, and for building contour terraces on easy slopes which have not been too badly cut up by gullies.—Para 7.7.

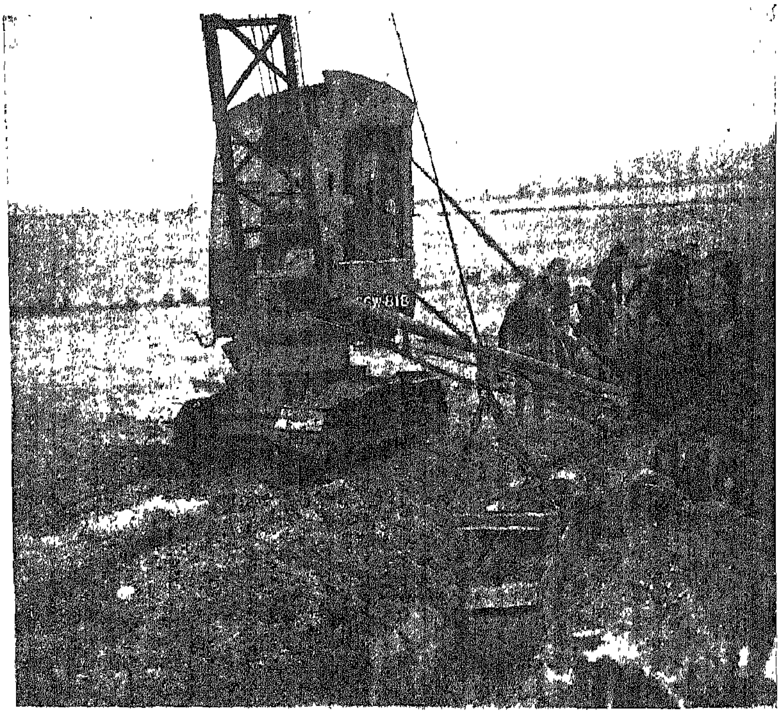


PLATE 15 (ii)

An excavator manned by land girls at work on a land drainage project in war-time Britain. This is a *static* machine as opposed to the commoner *mobile* type.—Para 7.8.

now worse than useless but can be made productive and fertile again. All this land is privately owned so it will also be for government to decide whether the original owners will be allowed to continue to farm such land after it has been reclaimed, or whether they should give it to service-men on some reasonable terms of tenancy.

7. 7. Third, there is the desert fringe all along the southern districts and in the Thal desert. Wherever irrigation stops and the cultivator is dependent upon a scanty rainfall of less than 15 inches, wind erosion is playing havoc, and incipient sand dunes are to be found spreading into good ploughland. The damage has increased because of the widespread destruction of all old trees and hedges. The cure for this desiccation is to establish a network of shelter-belts and wind-breaks and these can best be sited upon a series of low contour bunds. [Even in practically dead flat land the value of contour bunding in improving the quality of the crops through a better conservation of all the rain that falls is most strikingly shown in the Hissar Livestock Farm] The contour bunds can best be made with the same type of terracer machine as we propose to use in the upland plateaux or with a scraper, roller-scraper or motor-grader. Where the rainfall is so poor that tree growth is difficult to establish, useful screens or wind-breaks can be formed by growing the tall cane grass (*munj* or *sarkana*). The pattern of this desert fringe forms a very irregular line through Hissar, Ferozepur and Multan districts and it applies to all uncommanded land where the benefits of irrigation have not been felt. For details see Chapter XII and areas para. 7. 10.

7. 8. Fourthly, there are numerous tasks for the type of machinery described as *static* as opposed to the *mobile* equipment so far discussed. The difference is that the mobile equipment moves while working the earth, whereas the static equipment remains stationary while its power is applied by means of cranes, excavators, scoops or grabs working within a small circle round the stationary machine. This type of equipment is chiefly used by the irrigation engineers in excavating canal channels but we can employ it profitably in various ways. One is in the digging of a series of new water ponds, and improving existing ones, many of which are in a dilapidated and neglected condition. The siting of new ponds forms part of our scheme for the better control of surface run-off throughout the uplands where the water shortage is acutely felt by man and beast every summer. See Plate 15 for excavator.

7. 9. Another alternative application of this static type of machinery is in the reclamation of stony stream beds which are

such a tragic feature of Kangra, where many square miles of once fertile land have been replaced by beds of boulders and shingle. Here the plan is to utilize these machines for building up a series of break-water bunds pointed downstream at an acute angle of 25 to 30 degrees so that they do not form a direct impediment to the force of the flooded stream. The spaces between this herring-bone pattern of stone bund and the original shore line will silt up rapidly owing to the stilling effect upon the flood water which drops its load of silt in the shelter of each bund. The ground thus reclaimed is immediately planted up with trees and grass. Without expensive stone facing or pitching many of these bunds will be reduced or destroyed by subsequent floods but the net gain of new land thus formed should be appreciable. The heaping up of stones and shingle can also be undertaken with the bull-dozer or angle-dozer.

7. 10. The following schedule gives some indication of the extent to which machinery can be employed in the reclamation of each of the above types:—

7. 10. *Estimate of Reclaimable Land.*

Serial No.	District.		Gross Area.	I. Requires Terracing.	II. Ravines.	III. Desert Fringe.
1.	Hissar	...	3,317,815	...	...	1,500,000
2.	Rohtak	...	1,437,271	...	...	700,000
3.	Gurgaon	...	1,440,537	...	...	300,000
4.	Karnal	...	2,012,742	...	...	400,000
5.	Ambala	...	1,193,692	250,000	150,000	...
6.	Simla	...	67,023	...	...	...
7.	Kangra	...	5,644,540	50,000	50,000	...
8.	Hoshiarpur	...	1,421,528	200,000	100,000	...
9.	Jullundur	...	858,606	100,000	...	
10.	Ludhiana	...	894,153	300,000	...	...
11.	Ferozepore	...	2,600,890	...	...	500,000
12.	Lahore	...	1,667,568	100,000	...	...
13.	Amritsar	...	988,230	50,000	...	...
14.	Gurdaspur	...	1,170,975	100,000	50,000	...
15.	Sialkot	...	1,004,670	50,000	...	...
16.	Gujranwala	...	1,473,542	200,000	...	...
17.	Sheikhupura	...	1,479,539	200,000	...	...
18.	Gujrat	...	1,458,151	200,000	200,000	...

Serial No.	District.		Gross Area.	I. Requires Terracing.	II. Ravines.	III Desert Fringe.
19.	Shahpur	...	3,071,407	...	100,000	400,000
20.	Jhelum	...	1,770,859	200,000	400,000	...
21.	Rawalpindi	...	1,311,768	200,000	300,000	...
22.	Attock...	...	2,680,437	700,000	500,000	...
23.	Mianwali	...	3,436,140	...	100,000	700,000
24.	Montgomery	...	2,721,510	...	...	300,000
25.	Lyallpur	...	2,249,049	...	...	100,000
26.	Jhang ...	...	2,169,231	...	...	100,000
27.	Multan	...	3,603,531	...	...	500,000
28.	Muzaffargarh	...	3,559,677	...	...	400,000
29.	Dera Ghazi Khan		3,475,769	...	50,000	300,000
	Total	...	60,190,850	2,900,000	2,000,000	6,200,000

IV. Ponds and stream banks say 1/30th of total area of province = 60190850 = 2006361 say 2,000,000 acres.

V. Main river banks, 1840 miles × 2 miles width = 2,355,200 acres.

7. 11. *Types of Machine.*—Apart from the general classification into static and mobile, the conventional description of machinery and the trade names used for them are somewhat difficult to follow. Tractors on caterpillar tracks are usually described in 5 classes as follows:—

I	D 8	horse power	113	(drawbar).
II	D 7	”	80	”
III	D 6	”	55	”
IV	D 4	”	35	”
V	D 2	”	25	”

The D 8s are too big for ordinary terracing work and they and D 7s are expensive in the field. Actually most of our work can be done effectively by using D 6s, 7s & 8s for the ravine reclamation bull dozing and D 4s for the lighter terracing work of which we have a vast amount to do. In the bulldozer type there are two varieties, one with a heavy blade which is raised by means of a block and tackle; this depends upon its own weight for its downward cutting action and is much more freely manipulated. The

other has a hydraulic control to regulate the position of the blade, which can therefore be made considerably lighter as it is not dependent upon its own weight and can exert the whole weight of the machine to make a downward pressure. The hydraulic dozer is therefore best for hard cutting, but the cable dozer for soft earth or forest clearing. The chief difference between the dozer and the terracer or grader type is that in the dozer the blade must be right at the front for using more or less as a battering ram, whereas the terracer has the blade suspended between two pairs of wheels and is therefore limited to reasonably level ground and cannot attempt very deep fills. To maintain caterpillar equipment efficiently in the field requires very close attention to the "drill" for greasing, oiling and immediate replacement of faulty parts. It also requires expensive subsidiary machines for greasing and transporting across-country to reduce wear by travel on the tracks. Figures 31 and 32, and Plates 14, 15 and 16.

7. 12. Amongst the special equipment for moving earth or stone we have to distinguish between a short carry and long carry. For moving material a few yards it is more economical merely to push it along with a cutting blade which throws forward and sideways. This is the typical dozer action. On the other hand if earth is to be carried for more than 200 feet distance as in the complete levelling of sloping land, or in the typical *wattbandi* operations of the Punjabi cultivator who insists upon making all his fields square, it may be more economical to pick up and carry the earth rather than push it. For this purpose the best machine is the carry-all scraper or "tumble bug" which not only cuts the soil but picks up in a bucket whatever soil its blade separates. This soil can be dumped as desired by operating a release lever wherever required. Figure 33.

7. 13. *Subsoiler.*—A very large variety of equipment is available for purely agricultural operations, such as disc ploughs and multiple harrows, but we should remember always that the object of our work is not to displace manual labour in the fields but to create fresh fields and better fields which will employ a larger number of men using the ordinary villagers' equipment. Amongst the purely agricultural machinery, possibly the one which will be of most use to us is the subsoiler or pan-breaker, which is a small plough-share attached to a powerful bar which goes through the soil at a depth of 1½ ft. to 2½ ft. and shatters the subsoil without turning over a furrow. (Fig. 34). This has the great advantage of leaving the fertile soil still on top but rendering the subsoil much more porous and absorptive. By this means the land if worked at an interval of say 2 to 5 years with the subsoiler would be kept capable of absorbing far more of the rainfall than

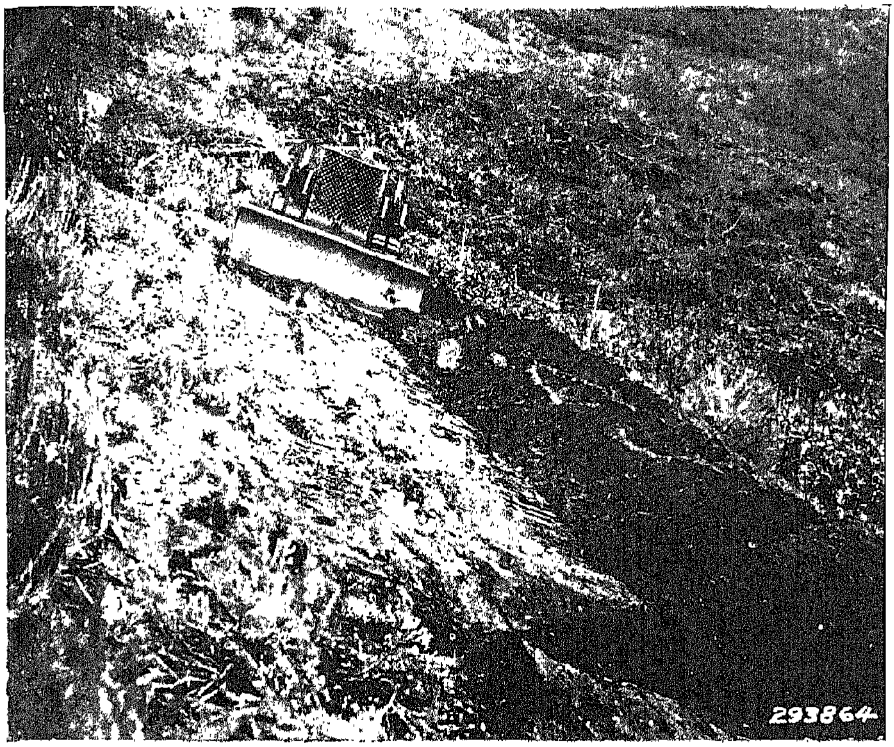


PLATE 16 (i)

A trail builder, which is a track tractor with a blade in front manipulated by hydraulic hoists, used to build most of the trenches on slopes upto 40 per cent. but compare Para 3.36.

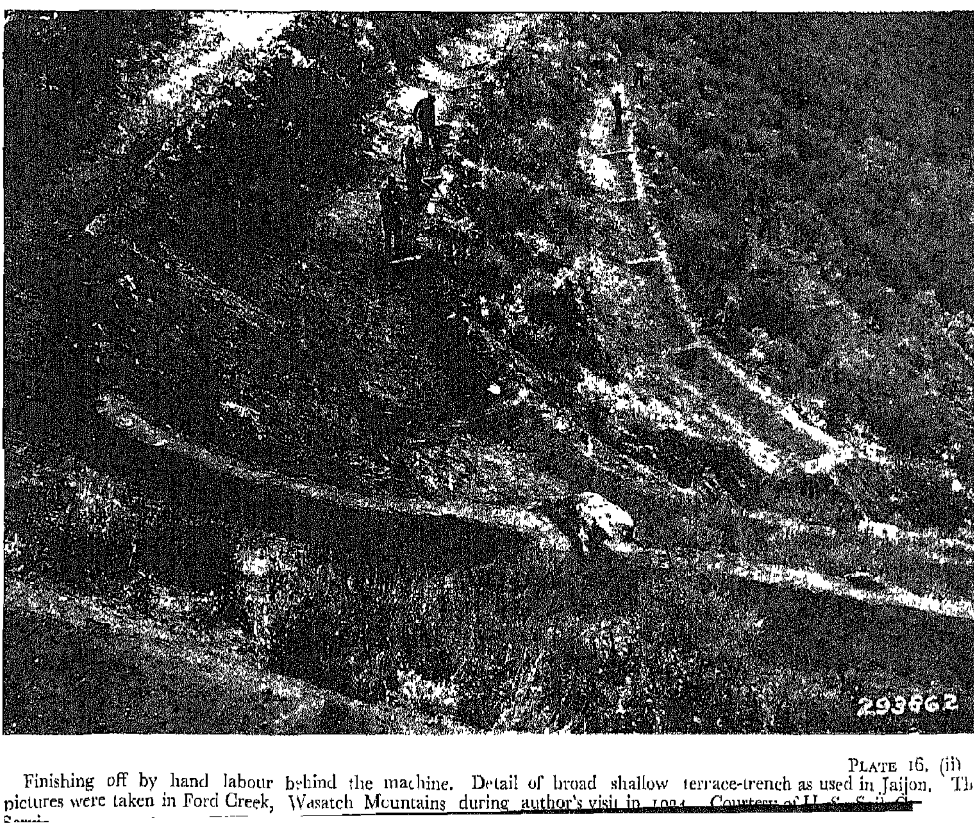


PLATE 16. (ii)

Finishing off by hand labour behind the machine. Detail of broad shallow terrace-trench as used in Jaijon. The pictures were taken in Ford Creek, Wasatch Mountains during author's visit in [illegible] Courtesy of U. S. Soil Co- Servic[illegible]

FIG. 32. ANGLEDOZER--WORKING POSITIONS

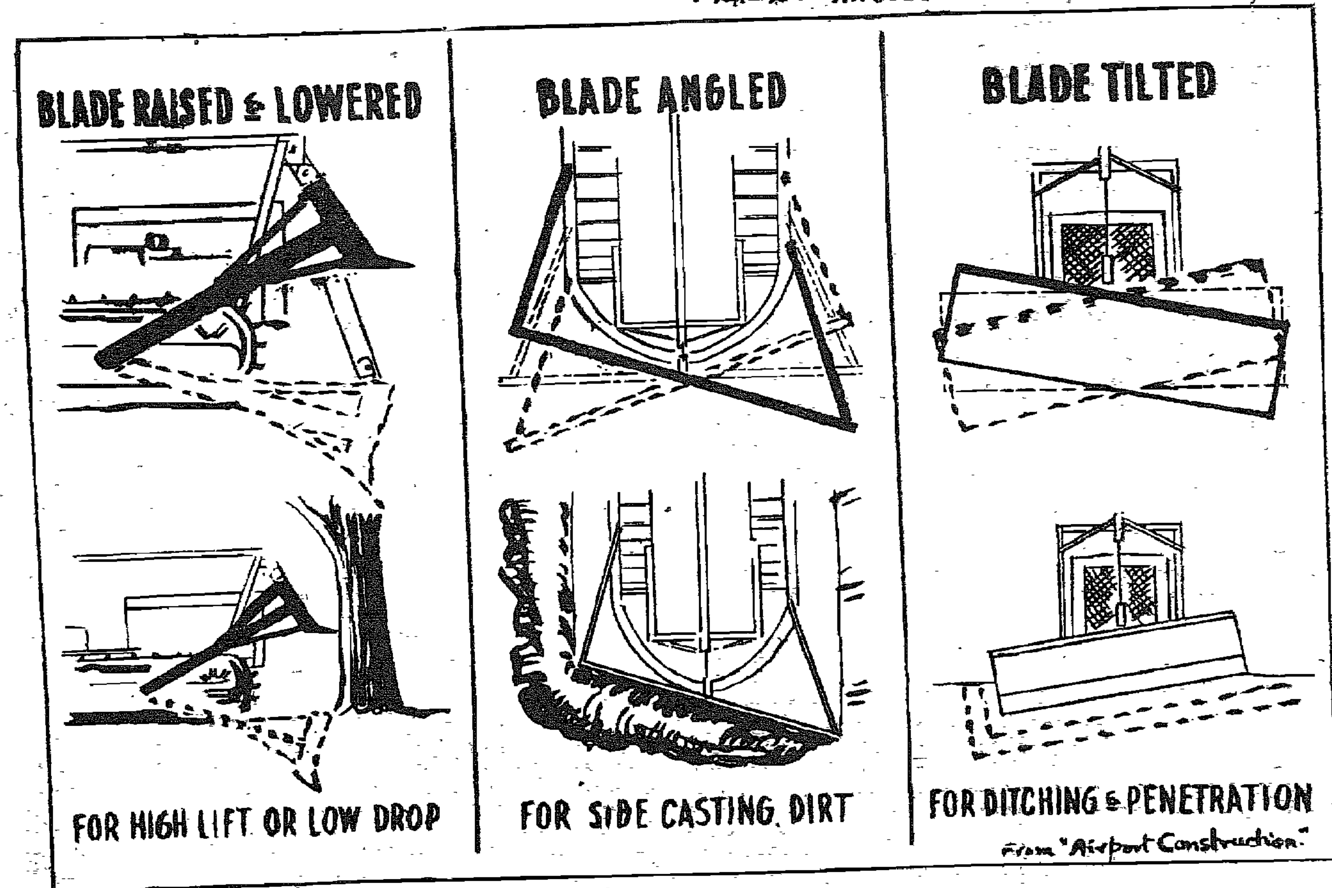


FIG. 33. CARRYALL SCRAPER CYCLE

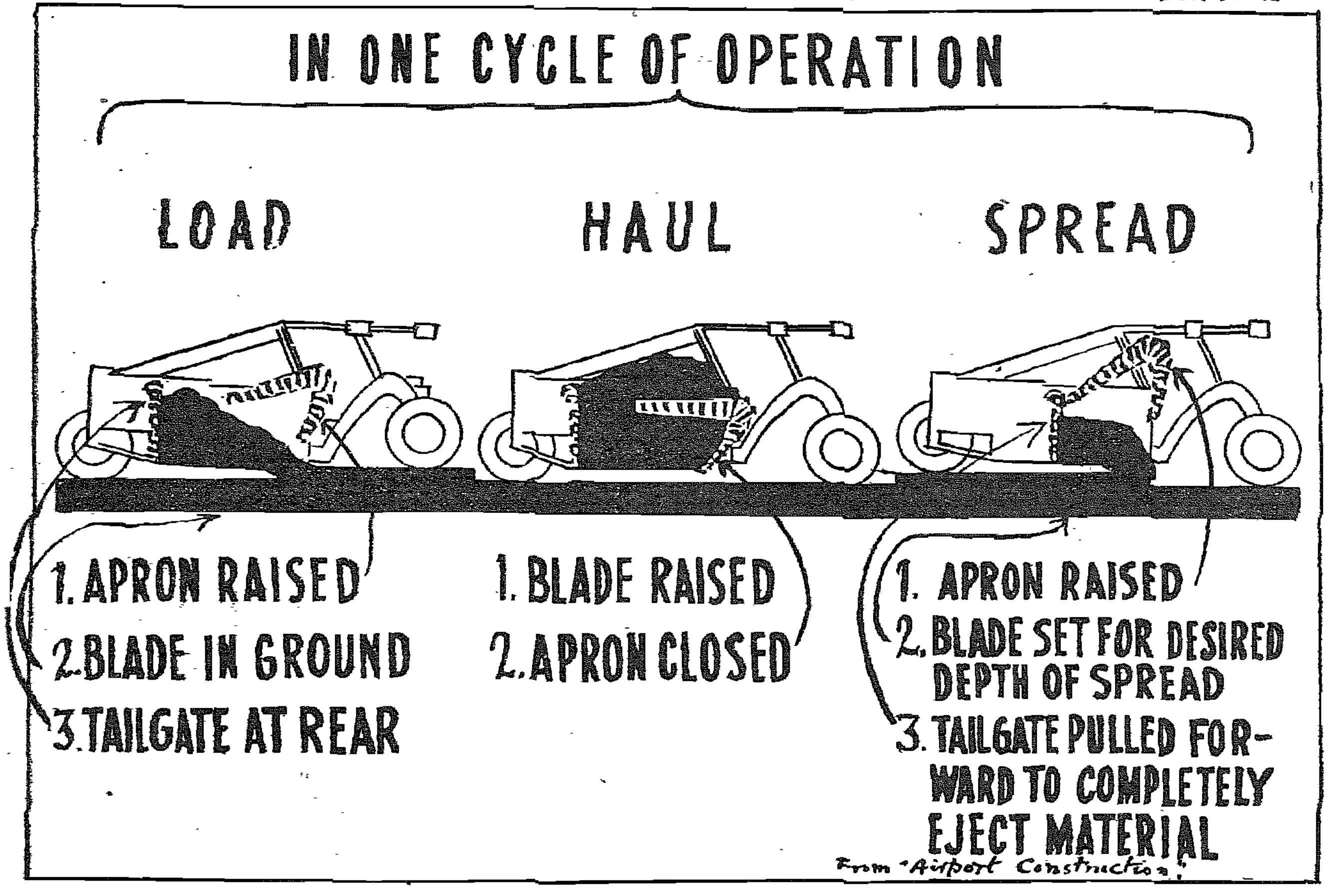
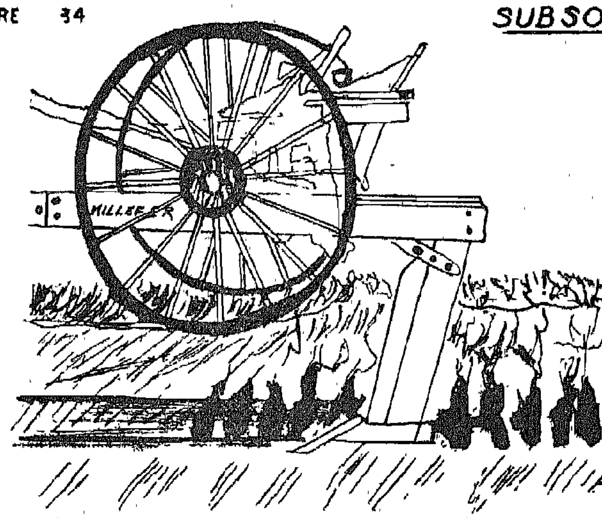


FIGURE 34 SUBSOILER



THIS CROSS-SECTION SHOWS HOW THE MILLEFER PANBREAKER LIFTS & SHATTERS A LAYER OF HARD DRY PLOW PAN NOTE THAT THE FERTILE TOPSOIL STAYS ON TOP- STERILE SUB-SOILS ARE NOT BROUGHT TO THE SURFACE TO RETARD SEED GERMINATION & ROOT GROWTH. ©

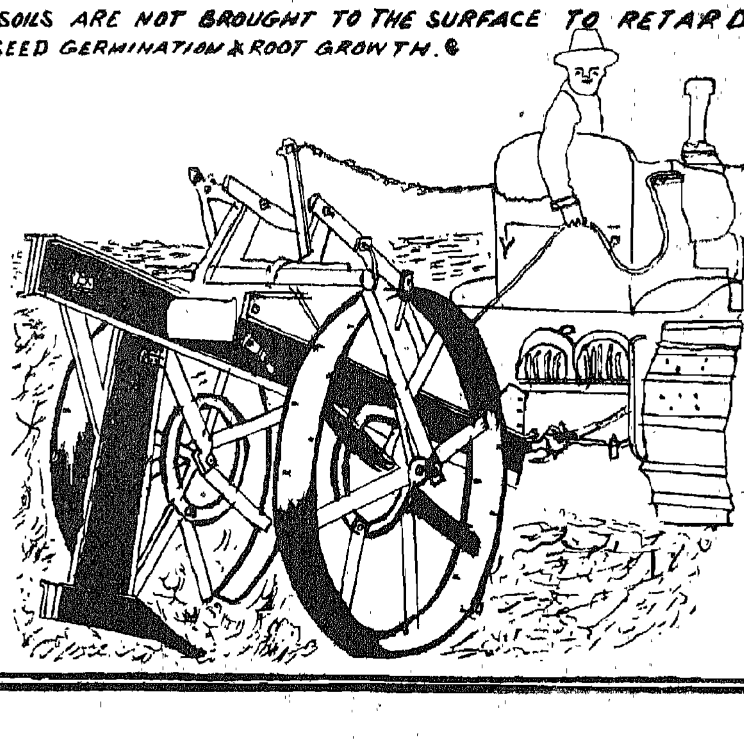


TABLE 7.14-A.

Bull-dozer operating costs per machine hour.

Approximate cost of owning and operating Caterpillar Diesel Tractors per hour under fair average conditions.

Under good conditions the fuel and oils consumptions will be slightly less thereby reducing the working cost, and similarly under severe conditions there will be a slight increase.

Although for purpose of calculation the tractor is written off completely at 10,000 hours, this does not mean that its life is ended by any means, but after that period the cost of owning per hour is very appreciably reduced.

	D-8 consumption	D-8 rate	D-8	D-7 consumption	D-7	D-6 consumption	D-6	D-4 consumption	D-4	D-2 consumption	D-2
Approximate Value.			Rs. 30,000		Rs. 26,000		Rs. 20,000		Rs. 13,000		Rs. 10,000
WORKING COSTS PER HOUR.											
Diesel Fuel	4 Galls	@1/4	Rs. 5.00	3 Gallons	3.75	2 Gallons	2.50	1½ Gallons	1.90	1¼ gallons	1.60
Petrol	1/8 "	@2/-	.25		.25		.25		.25		.25
Lub. Oil	1/8 "	@6/-	.75	1:10 "	.60		.60		.50		.40
Grease	1/4 "	@-/8/-	.12		.12		.12		.12		.12
OPERATORS & CLEANER. *Also Maintenance.* (2500 hours per year)		say	1.00		1.00		1.00		1.00		1.00
			7.12		5.72		4.47		3.77		3.37
FIXED CHARGES PER HOUR.											
Depreciation—Complete write off in 10,000 hours			3.00		2.60		2.00		1.30		1.00
Repairs @ 1/2 original cost spread over 10,000 hours			1.50		1.30		1.00		1.65		.50
Interest on Investment @4% ...			.12		.10		.10		.05		.04
Total			4.62		4.00		3.10		2.00		1.54
TOTAL			11.74		9.72		7.57		5.77		4.91
		say	Rs. 12/-		Say Rs. 10/-		Say Rs. 8/-		Say Rs. 6/-		Say Rs 5/-

Prepared by Messrs Buckwell & Co., Agents of Caterpillar Diesel.

Since the above was prepared the cost of these machines has risen approximately 11%, but oil and diesel fuel is up to 30% cheaper when bought on Government contract rates. Several experienced R E officers are of opinion that 10,000 hours life is unjustifiably optimistic and that 6000 hours should be the basis of calculation. The hire rates for Army equipment laid down by the War Office allows only 4000 hours, so their rates are very much higher.

it does after ordinary ploughing. Using a subsoiler at 8 ft. or even 10 ft. apart would make a big difference to the absorptive capacity of any field. A similar but heavier instrument is the "rooter" which has 3 heavy subsoiler knives mounted and capable of cutting to a 40 inch depth, the knives being about 2½ ft. apart. The upheaval in the subsoil caused by this implement is terrific, but it needs a D 7 or a D 8 to pull it.

7. 14. *Cost of reclamation with mechanical equipment.*—In America where terracing is being done on a very large scale, highly trained engineers and skilled machine operators are invariably engaged. Wages there are high, yet the cost is comparatively small and well within the means of the smallest farmer. In most states "extension" work in agriculture is carried out on the co-operative system and the method of financing terrace projects is interesting. The county board of revenue, which is the appropriating board of the county, underwrites the purchase price of the terracing plant and the Department of Agricultural Co-operation make a charge to the farmer on whose farm the work is being done of three dollars (twelve rupees) per hour for the terracer and four dollars (sixteen rupees) per hour for the bull-dozer for the actual time spent on the job. These charges include a tractor operator and machine operators for the terracer and an operator for the bull-dozer. The charge also includes a surveyor and rodmen who are engaged on laying out the terrace lines just ahead of the machinery. The surveyor is usually the foreman of the party. Of course the hourly rates include fuel-oils, grease, lubricants, and depreciation. Under normal conditions one dollar per hour goes towards the purchase price of the equipment and instruments. The working and basic costs of the various types of machine is given by Caterpillar Tractors agents in schedule 7. 14A. on a basis of machine hours.

7. 15. To convert this basic cost figure into an acreage cost brings in so many factors that it is foolish to give any empirical figure. The bull-dozer reclamation of ravined lands by No. 6 Group Indian Engineers at Kharian in Gujrat district has itself been very expensive because it has built very large and broad fields out of some of the worst ravines in the Pabbi Reserve, and their work was essentially to train drivers, not to reclaim land. It has however indicated that in large blocks of ravines, 10% of the area can be made cultivable fields at a cost of 50|- per acre, provided only the *nala* bottoms are widened and bunded. If half the total acreage is attempted costs go up to 400|- per recovered acre, whereas a cent per cent recovery in deeply ravined land will cost at least Rs. 800|- per acre. This is for fields. For affores-

square mile will have to be met as a charge repayable by him along with land revenue but spread over say 20 years. So that government would get 4800|- a year as refund, plus a large increase in land revenue assessment which might amount to 4|- per acre per annum or 1280|-, or say 6000|- a year steady income against an outlay of 128000|-.

D. If government leases the land on the same lines as B above the cost will be 128000|- immediate outlay plus 320|- annual lease money and the return in *batai* will be 25|- per acre on half the area or 7000|- per annum as a continuing steady income for 50 years.

7. 20. *Tasks for mechanical equipment under postwar programme.*—

(a) The area of ravined but reclaimable land is given in the table 7.10.

(b) *Extensive work.*—Aiming at 10% reclamation we have to reclaim 1|10th of the total or 190,000 acres and this task should in theory be well within the capacity of the Rs. 10 lakhs purchase of machinery over a 5 year period, but in practice we cannot allow such dilution of forces over the total area of ravined land as we could not control it effectively, and much running time would be wasted in moving over great distances between jobs.

(c) *Intensive work.*—Aiming at 50% we have a task of reclaiming ½ of the total or 950,000 acres which with the 10 lakhs machinery working ¼ acre per day, each machine would reclaim only 1500 acres a year (20 machines for 300 days a year).

(d) Some compromise between b and c above seems to be the solution, but before proceeding further it seems desirable to ascertain whether government would be prepared to consider the leasing of suitable areas for reclamation and subsequent farming with government as landlord.

7. 21. *Specific Instructions regarding contact and survey.*—Before the mechanised squad arrives in any given area which has been allocated for reclamation a great deal of work is necessary:—

(a) the consent of a majority of the owners to have their land treated for which they should be warned that they must pay a share, upto whatever upper limit government may fix from time to time—at present 40|- per acre.

(b) from a trial period of reclamation, say 1 month for that area, a number of land types will be differentiated and an appropriate cost of reclamation worked out for each type.

(c) a survey squad will work ahead of the machines in preparing a contoured plan for the whole block of land to be worked over and separate out these land types. For ordinary *darrar* as in Ambala or Gujrat with ravines of not more than 20 ft. depth these classes will be:—

(i) plateau land which needs only wattbandi but no terracing.

(ii) plateau land which needs wattbandi and a considerable amount of levelling either because of slope or because it is slightly gullied

(iii) slopes too steep for fields and which will be roughly contour trenched and allocated to grass and tree production, including orchards.

(iv) land too steep for contour trenching which can be afforested or grassed after cutting narrow *gradoni* shelves with a D 2, see Figure 35.

(v) *nala* bottom land, part of which can be made cultivable behind earth bunds but majority of which will be afforested for torrent control.

(d) an average cost for each of these types will be worked on the basis of the trial period and these figures will be applied to the whole of the future work in the area or group of villages to be covered in one working season.

(e) the percentage to be recovered from owners or occupiers should normally be 50% for all land rendered fit to bear field crops and which can be expected to produce a yield better than the same field produced before. For land allocated to grass and tree production the recovery should not be more than 10% as cash yields will be slower accruing and it is in government's interest to encourage dedication of land for this purpose.

(f) a revenue representative will be responsible for the detailed measurement of all land reclaimed and for the assessment and recovery of the owner's share as an arrear of land revenue, or a *taccavi* loan.

(g) a consolidation officer will be attached to the party to ensure that the consolidation principle is fully applied to all reclaimed land, so that small and broken holdings may be consolidated at this time, irrespective of whether the village has previously been consolidated or not.

(h) an experienced agriculture officer should also be in the party to advise on any change in choice of crop which terracing may make advisable, and on the provision of fruit trees, grass seed, etc.

(i) the planning of field work should aim at avoiding interference with normal sowing. Occasional destruction of growing crops will be inevitable but must be kept to the minimum and can to some extent be avoided by planning the work ahead and warning owners not to sow in areas to be worked over in a given sowing season.

7. 22. *Waterlogging.*—The Central Board of Irrigation in November 1931 recorded its provisional opinion that reclamation of waterlogged and alkaline soils was definitely possible by lowering the subsoil water-table except where a hard and impermeable crust had formed. Even in this latter case it appeared that reclamation was possible—and perhaps economically possible. Prior to the undertaking of any scheme for the reclamation of salt-affected lands, it is essential to conduct an examination of the subsoil by experts. An efficient surface drainage system for the rapid removal of storm water in areas subject to appreciable rainfall plays a most important part in checking the rise of the subsoil water-table. The converse holds good. When the water-table shows signs of falling due to natural causes, the retention of rainfall by obstruction of drainages and the construction of tanks tends to check the fall. In September 1938 the Board issued *Publication No.* 17 entitled "Notes on Waterlogging and Land Reclamation in the form of a Questionnaire". Information received from the various provinces is listed under 26 questions appertaining to waterlogging and 23 questions concerning land reclamation.

At the Research Officers' Meeting held in Lahore in 1939, Dr. Mckenzie-Taylor defined the water-table in terms of saturation of the soil, and stated that unless the soil was saturated the pressure transmission could not be measured by a manometer. This is of importance in connection with forecasts regarding the probable area of land that may become waterlogged due to the rise in water-table. In the Punjab the well readings showed that when the water-table approached the soil crust, the rate of rise decreased, and that the rise ceased when the water-table touched the underneath surface of the soil crust.

7. 23. When the soil crust is of greater thickness than 6 feet, evaporation is likely to be a minor factor in water-table control. Recent research has altered the views held regarding the part played by the rise of water-table in causing the deterioration of land due to *thur*. In the Punjab land has gone out of cultivation due to the appearance of *thur* with the water-table at a depth of 40 feet below the surface, so there appears to be no connection between this water-table and the salts causing the deterioration. Under these circumstances therefore the drain-

PLATE 11 (i)

Failure in 1906 Kalachitta checkdams due to water finding its way round the end of the bund & undermining the whole structure; Para. 6.28.

PLATE 11 (ii)

A more recent failure in 1906 work owing to undermining of the wall by water. With such a flat profile failures are frequent.

ing of waterlogged land appears to be feasible merely by digging a fairly comprehensive series of drains and cross drains and for this purpose the use of mechanical excavators should be of the greatest value.

7. 24. *Use of Explosives in Reclamation of Deep Ravines.*—The only recorded use of explosives in soil preparation for afforestation is described in a paper written in French by a Dutchman E. C. Abendanon printed at the Hague, 1935. This advocates the drilling of a series of holes for blasting the hard rock strata in dry shallow clay soils in order to deepen the absorptive layer, the depth of the holes being fixed by the depth of which the tree roots could normally penetrate in the unimproved soil.

With the improvements in blasting technique brought about by the war, we have experimented with the use of explosives for knocking in the vertical sides of deep gullies. An 8″ diameter hole is bored for a depth of 10 feet, using the large earth auger which is in the equipment of most field engineer companies. This hole is sunk at a point 10-12 ft. from the broken edge of the earth cliff and the explosive charge of from 12-20 lbs. of ammonal lowered into the hole and well tamped down before being fired. The charge can be fired singly or in a series at points along the edge of the earth cliff by means of an electric discharger. The chief value of this operation is to throw a large volume of loose earth into the *nala* bottom, where it can be used for building a series of earth dams to pond back flood water, either as a temporary measure while the *nala* bed downstream is being reclaimed, or as a more permanent improvement entailing the fitting of cement or rock rubble escapes on each bund. Plate 11 for this use of explosives.

Chapter VIII.

DIVERSION AND STORAGE OF FLOOD WATER.

8. 1. *Water Economy.*—Much discussion has centred round the statements of experienced irrigation engineers that the Punjab is rapidly approaching the end of its river supplies, and it is well known that with the completion of the Kalabagh weir on the Indus, the whole of the cold weather free flow of the rivers will have been harnessed. There still remain other perfectly good alternatives, namely

(i) high dams in the hill catchment areas,

(ii) tube wells, and ordinary wells,

(iii) spreading and storage such as the old-fashioned but effective basin irrigation of Madras and Bundhelkhand and the tanks of the C. P.

(iv) water spreading as practised by the Navajo Red Indians and developed under the Rooseveldt regime to a high pitch of efficiency.

(v) storing every drop where it falls, as is the basis of all contouring and *wattbandi.*

(vi) deliberate concentration of run-off into the centre of artificially formed small catchments.

8. 2. *Cash Value of Extra Moisture.*—The extra yield obtained as a result of husbanding a little extra moisture by diverting and storing a September storm is well illustrated in the figures produced on the New Pusa farm of the Imperial Agricultural Research Institute by C. H. Parr whose plots of wheat and barley all showed an increase of from 3 to 5 fold as a result of extra September water, whereas even good winter rains are wasted owing to the bad sowing results when September water is short. He also correlates the shortage of September moisture with very heavy losses of sowings which did not mature, and suggests that the tail end of the river floods in that month should be made better use of by spreading on the fields in *barani* tracts by an adventitious system of overflow canals or extensions beyond the tail of the regular irrigation. (C. H. Parr in *Indian Farming*, March, 1943.)

In the drier states of the American Middle West where the rainfall is somewhat similar to our unirrigated Punjab districts

PLATE 17 (i)

The Bihar Forest Department technique of siting a checkdam and spillway at a point in a nala bed from which a diversion ditch carries off the surplus & allows it to percolate into the hillside: Para 8.5.

PLATE 17. (ii)

with 18 to 20 inches of rainfall, the addition by spreading one inch depth of water and adding this to the average available subsoil moisture increased maize production by 5-7 bushels per acre. (T. B. Chambers "Postwar Opportunities for Agricultural Engineers in Soil and Water Conservation." *Agricultural Engineering* for June, 1944).

8. 3. The collection of stagnant water in order to allow it to seep into the ground is subject to suspicion from the point of view of malarial control, but in the type of water-spreading now contemplated the period during which free water surfaces are ponded up is usually less than is required for a mosquito larva to hatch out. In cases where this proves not to be so and the act of spreading water actually does increase the incidence of the malarial mosquito, the war-time experience in fighting malaria with new and powerful insecticides such as DDT and the Imperial Chemical Industries' 666 must be brought into use, for the fact remains that water made available for crops is the life-blood of the country, and our efforts to make that water available must not be frustrated by others' mistaken zeal for the health of the cultivator.

8. 4. *The Effect of Reservoirs in Reducing Floods.*—In Sind the river banks are generally so far apart that the area between them provides a basin for temporary storage, and thus retards the flow and prevents excessive floods. In the Deccan they have no experience with reservoirs constructed for the purpose of retardation, but since the construction of the Bhandardara Dam the maximum flood had been reduced to 15,000 cusecs as against a 44,000 previous flood. In Madras the Mettur Reservoir has turned a flood peak of 120,000 cusecs into a regulated discharge which rarely exceeds 55,000 cusecs. The proposed Bhakra Reservoir on the Sutlej should give us a spectacular reduction of peak floods below the previous uninterrupted streamflow peak of 400,000 cusecs.

8. 5. *Percolation Trenches.*—In the 1890s the Tirolean forest engineer Seppet made horizontal trenches in the neighbourhood of torrents. The object of these *Sickergraben* was to catch the run-off from bare patches in the meadows along the boundaries of woods, so that it could be passed slowly into the underground streams. From this he expected a delaying and levelling effect on streamflow and a reduction in flood peaks. He laid down that the trenches should strictly follow the contour and spaces between should vary from 12 to 30 feet according to slope with the trenches 20" average width and 10" deep, the excavated soil being heaped on the lower side.

Similar trenches are used in dry countries in the Orient and under the name of *girapoggi* have been in use in many Italian areas since long. Their aim is to increase soil moisture and plant cover and under certain circumstances to favour the water-table level.

To destroy the erosive effect of run-off, trenches were recommended by the Frenchman Polonceau in 1847 and also by the Florentine engineer Duranti. They are usefully employed today in Italy. However the depreciation of meadows cut up by trenches and heavy cost of maintenance not usually reported, are against this method, while danger of slips on unstable slopes is increased by the accumulation of water in the trenches. Actual experiments in Ederbache-bei-Otz resulted in failure in this way owing to the trenches on slopes becoming waterlogged and starting a land-slide. Speaking from our own experience with landslips, deep trenches on unstable ground or on steep stopes should be avoided.

It is suggested that the best adaptation of this percolation trench is in running out horizontally on both sides of check-dams which have been built across streams; trenches to be aligned so that flood water can enter and move slowly along them, hence they really become *diversion ditches*. Where however the slope is steep or liable to become water logged a simple narrow platform on the lines of the Italian *gradoni* (meaning "platform") is probably the best way of providing lodgement for planting and sowings. (Diagram 35).

PRINCIPLE GRADONIS ARE 20-30 FEET APART BUT HAVE SMALLER SHELVES CUT ON INTERMEDIATE GROUND

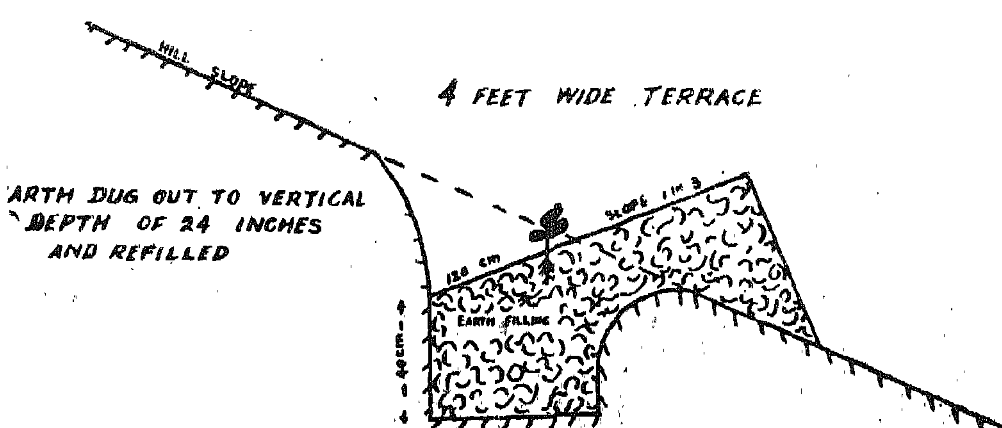


FIGURE 35.

PLATE 18 (i)

Leakage in a watt caused by a rat hole through which the whole amount caught by the watt has drained away enlarging the hole as it escaped.—Para 6.9.

PLATE 18 (ii)

A brick water-holding bund in the Julaha branch of the Dholbaha Cho in Hoshiarpur, built in 1945 by Sapper and Miner artisans borrowed from KGO S & M, Roorkee. By using the slot for planks the water can be headed back to a depth of 8 feet and used for irrigation of adjoining fields over some 10 acres.—Para 8.7.

8. 6. *Contour Trenches.*—Our experiments with *contour trenches* in the Siwaliks indicate an immediate improvement in flood conditions. Out of three small catchments of about 25 acres each at Polian above Jaijon, one was more or less completely trenched with accurately levelled trenches, each 10-foot trench holding 25 cft. or 156 gallons of water. Trenches cost 2 annas each and the cost per acre of trenching, gully plugging, and planting and sowing grass and trees was about Rs. 8 per acre. Run-off measurements were taken but only one severe storm occurred during the period observed. In it 2¼ inches of rain in 8 hours gave a peak flow of 4.7 cusecs and a yield of 78000 cubic feet over a period of 10 hours from the untrenched but no measureable yield whatever from the trenched area. Considering that the trenches were new and that practically no fresh vegetation had yet come in on the berms, this gives a convincing picture of the value of contour trenches. The grass yield from this area has improved steadily and the grass is now so thick that from the opposite hillside the trenches are no longer visible though they have not silted up at all, see Plate 4.

8. 7. *The Use of Ground Water in Torrent Beds.*—The use of underground water pumped up from the beds of torrents has been brought to a high state of efficiency by the California citrus growers. The topography of their foothills is very similar to our Siwaliks, with catchments of low hills covered with a natural growth of low scrub jungle which has in the past been grossly misused by fire, grazing and indiscriminate destruction. The water available from the free flow of the torrents in both places is limited to a matter of a few hours after infrequent rain-storms, after which the stream dries up but the sandy bed contains a large amount of stored moisture. In most of the California beds there are ledges or outcrops which force this stored water to near the surface or pond it back at definite places underground, so that it is accessible for pumping, but in the Siwalik lower fringe this is seldom the case near the hills and the water drops to a much deeper level below the outlying plains, though along the courses of torrents it keeps fairly high. We must therefore trap it wherever it is near the surface—i.e., either while it is still confined to a definite bed within the Siwalik hills, or at places in the plains where the water level keeps reasonably high and steady.

This can best be accomplished by a judicious mixture of the check-dam technique which has been worked for a whole catchment, the Bachoi and Maili Cho, by the forest department. In addition we intend the erection at suitable natural sites for larger water-holding dams, the latter work being more within the pro-

vince of the Irrigation Branch, though there is no reason why minor projects of simple engineering work should not be carried through by the local forest staff, supplemented by Sapper-trained masons, and provided that the site, plan, and estimate have been agreed to by Irrigation Branch officers. See Plate 18.

8. 8. *Diversion of Torrent Water.*—Intentional diversion of water across a hillside is frequently a necessity, as when the head of a landslide has to be kept as clear of subsoil drainage and surface run-off as possible. The alignment in such cases should be steep enough to ensure quick clearance of the ditch water, but any tendency to erode into a gully must be checked by stepping it down with stone sills at intervals. Ditches of this sort are also often justified for leading away hillside drainage from above a block of terraced fields, because it is the accumulation of drainage from uncultivated land above, which is often responsible for the breaching of watts and the subsidence or breakdown of terrace walls and terraced fields.

8. 9. An entirely different use of diversion ditches is for *water spreading,* the technique of which has not yet been fully worked out for our varying Punjab conditions, but should be of the very greatest importance wherever the water-table is sinking, as it is in the Bist Doab, or where the total rainfall must be caught and fed into the ground in order to produce crops or vegetation in the arid zone.

8. 10. Where torrents have been partially tamed and the flood water can safely be handled by means of a series of low but strong bunds across the tail of the flood channel, the water should be led off into fields or stock ponds or seepage meadows by means of a diversion ditch, which must be aligned to carry the surplus from a spillway at the side of the bund across-country to wherever it is needed. In the case of the Hoshiarpur Siwaliks the distance from the hills to the tail varies not only with the total volume of the flood but also with the progress in our conservation work upstream, and may be anything from 4 to 14 miles from the foot of the Siwaliks. The two flood channels of the East or White Beyn and the West or Black Beyn traversing the Bist Doab are partially dependent upon these torrent tails for their flow, but the bulk of the Beyn flow is derived from surface run-off from the plains areas below the hills and it therefore carries floods out beyond the zone of the ordinary Siwalik torrents.

8. 11. Where water can be held up by a bund closing the channel, as is being developed by the Irrigation Branch at various points on the Beyn channels, diversion ditches should be of value

for transferring the surplus flood water out into a network of contour ridges. Where the land is already fairly fully worked with well irrigation, the only land available for such networks will be the uncultivated waste, but even so the recruitment to the water table by increasing the seepage should be of the utmost value.

8. 12. The *San Dimas* valley in Southern California offers a good example of what can be achieved by water diversion. Flood flows originating in the 19 sq. miles of San Dimas Canyon are regulated by 2 reservoirs and diverted through a 2.7 mile concrete channel (capacity 3,500 cubic ft. per sec) into a third reservoir. This entire storage may be utilized for irrigating 2700 acres which constitute one of the most productive citrus areas in Los Angeles County. This system made it possible to conserve the entire runoff of the heavy storm of March 1938, amounting to 9,365 acre feet, and that of the storm of January 1943, amounting to 6,835 acre feet. This salvage created an asset worth at least 15 dollars an acre-foot for irrigation use. The rise in water-table underlying this agricultural area, since 1938, has ranged from 65 to 175 ft.

8. 13. Another example is seen in the Ruhr valley in Germany where the entire water requirements for a population of over 3½ million in an industrial district is obtained by elaborate seepage arrangements which hold back and store in the underlying gravel almost the entire stream-flow of the Ruhr river. Seepage basins away from the river bed are excavated through the top clay in order to reach the more porous underlying gravel, and special precautions are taken to prevent the accumulation of sludge which seals the surface and reduces the porosity.

8. 14. *Californian Technique for Water Spreading.*—Extensive spreading was first undertaken in Los Angeles County in 1906 at the mouth of San Antonio Canyon. Since then, some thousands of acres have been developed as a percolating area, utilizing one or more of the following methods:—

(1) the ditch and furrow method, (2) the basin method, and (3) percolation of regulated flows in wide natural stream beds. All three have modifications or variations, and often are used in conjunction with each other.

8. 15. *The Ditch and Furrow Method.*—This is generally used in areas of very rough or sloping terrain, where the water at times may have a heavy silt content. Canals and ditches are laid out with sufficient slope to prevent deposit of the suspended material, yet flat enough to prevent scour of the channel. Due to variation of soils across the spreading area, the proper slope

is often quite difficult to determine and may have to be corrected after construction by installation of check gates or sills. A modification of this method is to install main canals, as broad as possible and with shallow depth, from which smaller ditches at regular intervals lead the water out and spread it over the ground, much in the same manner as with flood irrigation. Water not absorbed by the flooded area flows to the next lower main distribution canal by which it is again distributed to a series of small ditches and thus to a new flooding area. Advantages of the ditch method and its variations are the low costs of maintenance and operation when the works are once correctly installed. When so constructed that the main channels may be flushed, this method will handle a greater silt content than any other type. It is more or less the same as the Dera Ghazi Khan *rodkoi* method, though the aim of the *rodkoi* is not to delay water in the channels but to turn the maximum quantity of silt-laden water out onto the embanked fields.

8. 16. *The Basin Method.*—In its simplest form this involves the construction of dikes or small dams at regular intervals across any abandoned natural channel or former river-bed area. The water is led into the upper basin by means of a canal and from succeeding basins, as each fills, it spills to the next; or the canal may extend past the first and feed basins on each side. From the last basin the surplus water is returned to the main flood channel. The upper basins may serve as desilting ponds and prevent excessive silt from being deposited in the lower ponds. During recent years the basin method has been used predominantly due to its economic use of land.

8. 17. *Stream Channel Spreading.*—In some form this method is practised on most major streams in Southern California. All of these streams are subject to high floods of short duration. On the lower valley areas this condition results in a broad, flat, sandy bed which is dry during the summer months and during most winter months normally has a surface flow covering only a small portion of its area. For several years conservation associations and county agencies have diverted the streams in these areas and spread them by various systems. Where the stream channels are composed of materials that tend to become sealed with puddled silt, the stream bed is broken up after the rains by tractors dragging cultivators or ploughs. In flat sandy stretches, the stream is diverted into ploughed furrows to ensure spreading over the whole of its flood-plane. In these ways water from a narrow meandering channel may be made to cover a considerable portion of a wide torrent bed.

PLATE 19 (i)

A good catch of rain in these contour trenches in Chohal continues to seep into the ground for several days after the storm and long after untrenched slopes are again bone-dry.—Para 8.6.

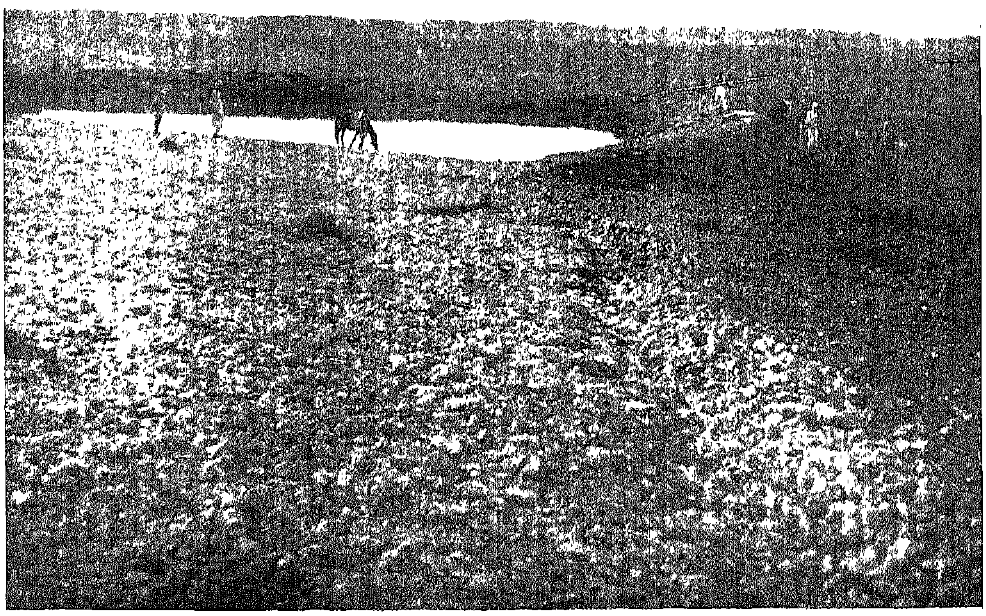


PLATE 19. (ii)

A water pond dug out on a gentle slope of the Salt Range. Foreground shows diversion ditch and ridge running out from the corner of the main bund so as to trap water from a larger area of hill side and enlarge the catchment.—Para 8.24.

8. 18. From flood marks and measurements of stream-flow percolation under existing conditions, the quantity of water which it would be desirable to handle in off-stream spreading grounds is determined. The ground-water level range and general soil characteristics indicate the percolating capacity. In Californian practice promising areas are checked to depths of 30 ft. or more by test holes to reveal the presence of clay lenses and other soil conditions which would have an important effect on the long-time spreading rate, then if a local water supply of a few cubic feet per second is available, a small sample basin is often tested for a period of several weeks to obtain further data on percolation rates. The lay-out is first made on a temporary basis, that is, with wooden intake, canal and basin structures, and a temporary sand dam for diversion from the stream. This is operated full scale before permanent outlets and bunds are constructed.

8. 19. Rates of percolation obtained have varied from initial values of 9 cu. ft. per sec. per wetted acre to final values under high ground-water conditions of 0.9 cu. ft. per sec. per wetted acre, the latter having held constant for many weeks of continuous spreading. In another sandy area away from the main stream bed a depth of 10 feet of water was absorbed daily over a period of several weeks, but once the surface was allowed to dry the rate of percolation dropped to a low figure.

When the normal water-table is less than 20 ft. from the surface it has been found that spreading quickly builds up a *water mound.* A ground-water mound is the tendency of the underground water surface to build up to a higher elevation immediately under the stream bed or spreading areas. Tests along the San Gabriel river have indicated that, when the normal water-table is less than 20 ft. from the ground surface, continuous percolation will result in the mound reaching the stream surface within a few days and thereafter will reduce the percolation rate. Hence underground storage at any location may be affected largely by the normal depth of the water-table. The water percolated in these basins, which would normally descend vertically to a low water-table, can only move away from the spreading area at its periphery. This indicates the value of elongated spreading grounds. Fortunately, the best natural sites are the natural stream benches of torrents and the adjoining sandy land. (F. B. Laverty; Correlating Flood Control and Water Supply in Los Angeles Coastal Plain. *Proc. Amer. Soc. Civ. Eng.,* June, 1945).

8. 20. *Other Local Applications.*—Diversion bunds used at Tamman in Campbellpur district take off from a very wide loop of the local torrent bed, where each summer a series of sand bunds is built up by hand labour and *karah*. These bunds start in the middle of the torrent bed and run at about 35-40 degrees across the path of the torrent, thus gradually leading the water towards parallel diversion ditches which run the water out into the adjoining cultivated land. The system is very primitive and often fails when the first storm brings a sudden and heavy discharge which carries away all the sand bunds in the torrent bed. The whole could be made much more reliable and permanent if the bunds were reinforced with live plants and the toe of each bund were protected with stone pitching or a post and brushwood crib.

8. 21. The Arabs of the Yemen and coastal Eritrea practise a similar water diversion by building a sand bund 30 foot high across their local torrent bed or *tug*, which is narrower and with higher banks than the Tamman torrent, and in fact more like our Pabbi or Siwalik torrents while these are still confined by definite banks and before they issue from the hilly catchments onto the plains below. The trapped water is led into larger fields surrounded with banks 6 or 8 feet high, somewhat after the fashion used by the Kamra villagers near Campbellpur.

8. 22. In 1934 I visited the Navajo Reserve, where the Navajo Indians of New Mexico have developed with the assistance of the Federal Soil Conservation Service a clever and enterprising technique of water spreading. The land is hilly with wide torrent beds, and the climate is so dry that crops cannot be grown without some form of irrigation. Stone dams only a few feet in height are built right across a torrent bed, with a low outlet at one or both ends of the dam. As the water is caught and headed up by the dam the overflow is led from the outlet and cut around the hillside beyond, and spread over several acres of levelled land. It is in fact closely akin to the *rod kohi* or torrent irrigation now practised in the higher plains of Dera Ghazi Khan, except that here the bunds are entirely made of sand and so have to be entirely rebuilt each year to replace the damage caused by the previous year's floods. The Dera Ghazi Khan technique is very primitive and is susceptible of much improvement by reducing the steep gradients of the irrigation channels which are so steep as to give rise to serious erosion along their path; and also by building *pakka* masonry or concrete outlets at suitable places. There are many other districts of the Punjab where the smaller torrents from neighbouring uplands could be

harnessed to irrigate a few acres of field and pasture land. The acreage of cultivation should be limited to whatever area can be thoroughly irrigated during the monsoon so that the land will produce a good *rabi* crop the following winter from the moisture thus stored in the soil. The surplus in years of full floods should not be used in fields but should be spread on sloping grasslands which have been previously contour ridged with 1 ft. high ridges and shallow ditches at intervals of 7 to 8 feet down the slope. The water must be fed into these ditches in rotation, starting with the topmost one in every case, and giving each ditch its quota before breaking the ridge and letting the water into the next below. If such irrigated pastures are kept closed to grazing until a new grass crop has been sown and become well established, most owners will soon learn that the land will yield a better return in cut grass rather than when grazed, but grazing if judiciously controlled can make good use of the aftermath of grass growth that is still on the ground after harvesting the hay.

The obvious place for this practice to be established is Kangra district, where many thousands of acres of good natural grassland are being cut to ribbons by shallow gullies as a direct result of over-grazing and failure to make any efficient use of the heavy rainfall.

8. 23. *Concentration of Run-off from a Block of Fields.*—On more or less level land with either a clay or a sandy surface and a low rainfall, it is suggested that for each block of 6 acres the central acre should be scooped out and the remainder all round sloped up to the perimeter, the aim being to get the maximum run-off from the slopes and concentrate upon keeping the middle acre as fully absorptive as possible for crop production. This is more or less the principle of the Thal desert patches of cultivation in the lowest re-entrants and hollows in the dunes. In the case of our artificially created hollow, clay lands would probably not need any special treatment except a little puddling to make the slopes throw off the water which falls on them, but in the case of sand, there are various salts now on the market (see para. 8. 24) which are recommended by the Irrigation Branch for mixing with the top layer of sand in order to render it impermeable. The amount of earthwork involved is of course a big item, but with the low count of days per year in which the arid zone farmer is fully employed (43 out of 365 in Attock) it is felt that man power alone could do much, apart from the possibility of getting machines on the job.

8. 24. *Water for Live-stock.*—One of the dominant needs of the Punjab, both hills and plains, is the better provision of water-ponds which will survive through the hot weather until

replenished by the monsoon. In many districts the cattle have to walk so far for water during the hot weather drought that this helps materially to pull them down in condition and very often renders them quite useless either for milking or ploughing, Many water ponds are so badly sited or so neglected as to be of very little permanent use. Those that are hopelessly badly sited from the point of view of having no appreciable catchment area should be abandoned, while those with reasonable catchments should be secured by repairing the bund, deepening the tank, and carrying wing walls out at an angle in order to secure a good catch of water from even minor storms.

For upland villages with no definite nala bed in the vicinity, the aim should be to have a whole series of ponds spread out so that each may catch its full quota of run-off. If the catchment is only a few acres there is no need for a masonry escape outlet, but where the catchment is anything over 7 to 10 acres in extent, some escape must be provided in order to avoid breaching. Sites should preferably be above the local road if that runs along the contour and is liable to suffer from erosion, but when the road itself runs downhill it is frequently possible to trap the road drainage and lead that into the pond.

For villages near a definite stream-bed which is deep enough to provide suitable sites for a dam or a series of dams in its bed. the usual technique already described for check-damming from top to bottom should as far as possible be carried out, in order to secure the safety and efficiency of the reservoir.

8. 25. *The Water Requirements of Live-Stock.*—Water plays such an important part in the normal development and existence of live-stock, that one cannot too much stress that animals should obtain a sufficiency of clean water. Even a temporary shortage of water has a detrimental effect on the development of young animals. At each stage of the animals' development water is the constituent which present in the largest quantities. In the case of cattle the developing foetus consists of approximately 90 per cent. water; at birth the body of the calf contains from 75 per cent. to 80 per cent. water, and the percentage of water in its body decreases as the animal grows older. In the case of a full-grown animal the body consists of water to the extent of approximately 60 per cent. An animal dies of thirst as soon as it has lost 10 per cent. of the weight of its body in water, although 50 per cent. of the proteins and all the fat may disappear without fatal results. All animals have a low resistance against a shortage of water, especially horses which cannot endure thirst for any length of time.

During periods of drought, when the animals receive large quantities of dry fibrous feed, it is desirable that they should have free access to an unlimited supply of clean water to soften the coarse feed, and to aid the movement of the masses of such feed in their alimentary tract. The dung of cows which have eaten dry hay containing 10 per cent. of water, contain 80 per cent. of water, in other words, the quantity of water in the dung remains comparatively constant, approximately 80 per cent. Benedict and Ritzman found that oxen on a high protein ration drank far more water than oxen on a low protein ration, the respective averages being 8½ gallons in the case of the former and 6½ gallons in the case of the latter, constituting a difference of 26 per cent. (Reference not recorded.)

8. 26. The characteristic climatic condition of our semi-arid areas is in the great difference between day and night temperatures, a low relative humidity, an intense luminosity, and many winds. All these conditions are caused by low rainfall. The dry ground has a low specific heat, and accordingly it becomes very hot during the day while the temperature drops very rapidly after sunset; the result is that there is commonly a difference between day and night temperatures of 30 to 40°F. In order to exist under such climatic conditions the animals must adapt themselves to the heat in particular; the water and salt reserves of the body tissues must remain constant. The animal's body is very sensitive to the accumulation of superfluous heat in the body. Factors like growth, development, and fertility of the animal are dependent on the ease with which the body rids itself of superfluous heat.

As a result of the fact that animals lose so much moisture during the hot season in the form of sweat, the body also loses a considerable amount of salt and for this reason it is advisable to supply the animals with salt during the warm summer months. As soon as animals consume large quantities of hay, they drink more water, and the proportion is usually three parts of water (by weight) to one part of hay (by weight) consumed.

8. 27. The quantity of water which animals drink also depends to a large extent on the stage of development. Young animals per unit of weight drink twice as much as full-grown animals. A shortage of water is consequently a serious drawback in the case of young animals. It causes a considerable retardation in their growth and development.

Milch cows drink more water than beef or plough cattle. A milch cow needs from 7 to 10 gallons of water for maintenance, and in addition she needs 2 gallons of water for every gallon of

milk produced. For maintenance and production the water requirements of milch cows can be reckoned at 4 to 5 lb. of water for every pound of milk produced, e.g., a 5-gallon cow will need 20 gallons of water per day. It is better to give milch cows free access to water. They will drink approximately 10 times per day, and the total amount of water drunk will be more than in the case of cows which are allowed to drink only 2 or 3 times per day.

8. 28. *Fish-ponds.*—The cultivation of fish in tanks and farm ponds has been greatly exploited and developed in Bengal but so far not in any of the drier parts of India. The Punjab climate should not however be regarded as making tank fish culture impossible, for in many parts of U. S. A. with almost as extreme a climate, farmers are making a good income from this source. The main drawback of course is the very high rate of evaporation. Allowing 6 feet of water to be lost annually by evaporation, the depth of the pond must be at least 12 or 14 feet if the fish are to survive through a couple of bad seasons.

The Fisheries officer under the Department of Agriculture has so far confined his restocking work to the placing of trout in running hill streams, but as the demand arises, arrangements will doubtless be made for the supply of fish to stock tanks where these comply with whatever limiting conditions are laid down.

Nothing has yet been done on these lines in the Punjab, but there appears to be a good future for this as a possible extra source of income to villagers, and as a welcome additional source of food. The siting and preparation of the pond should follow generally the lines laid down for live-stock water ponds, but extra precautions should be taken to ensure a minimum of silt getting into the pond, as an overdoze of silt in the water is liable to kill off even the hardiest fish.

American technique provides for the pond to be fertilised periodically with artificial manures in the same way as it is applied to fields, but little is known of how far this would be advisable under our conditions.

8. 29. *Water Tanks for Livestock and Fish.*—Long wing walls and diversion ditches to trap storm water and lead it into the tank are essential, as heavy evaporation losses have to be met. Avoid direct village drainage from the *abadi* because the drainage from streets and homes always contains impurities.

The following recipes are for the use of staunching materials:—

(1) Sodium carbonate 10% added to the soil.

(2) Kashmir bentonite 2% added to the soil. (*Pb. Irrig. An. Rept.* 1943).

(3) 1: 3 cement plaster reinforced with 1" netting. (*U. P. Irrig. Res. Tech. Memo.* 14, 1943).

(4) 1: 2: 4 cement concrete slabs 2" to 3" thick but these need a good joint filler to waterproof the joints.

(5) soil cement, made of sandy soil selected to contain 15% of clay. Mix 1 part of cement to 10 parts soil measured loose by volume, or 1 sack of cement to each 3½ cft. of sand, plus 2 gallons of water (L. G. Williams in *Civil Engineering* for April 1944).

(6) bitumen—impregnated material, e.g., gunny bags sandwiched in soil after soaking in bitumen.

(7) plain compacted soil beaten with a roller or beater into a compact mass, working completely over the whole of one 4" layer before starting on a second: the water-proofing effect wears off with frequent wetting and drying. A 3-foot wide "sheep's-foot" roller can be pulled singly by two pairs of bullocks or in multiple by a D 2 or D 4 tractor.

Chapter IX.

SOIL DENUDATION AS AN ADVERSE FACTOR IN RIVER SUPPLIES.

9. 1. *Central Board of Irrigation's Views.*—The Central Board of Irrigation at its 8th meeting in 1937 drew attention to the Proceedings of the British Empire Forestry Conference, South Africa, 1935, with particular reference to the 'possible dangerous effects of deforestation on irrigation in India. It pointed out that these effects are:—

(a) the increase of intensity of floods,

(b) the decrease of the dry weather flow in rivers.

The former means greater capital expenditure and more expensive maintenance on canal headworks, thus possibly making otherwise productive projects unproductive, and difficult to finance. The possibility of damage to existing works also must not be overlooked. In addition, and what is most important of all, there is the greater tendency to flooding of vast tracts of country. A decrease in the dry weather flow of rivers would have a most serious effect on those cultivators who rely on canal supplies to mature their crops. Even those who rely on irrigation from wells might be affected by lowering of the sub-soil water-table.

These detrimental effects have already been noticed in some of the smaller river basins. Although there is no absolute proof of the larger rivers yet having been affected by deforestation, the Board is of the opinion that India cannot afford to neglect the experience of other countries. The problem is not usually a provincial one, as most of the basins of larger rivers lie in more than one Province or State, and deforestation in one administration may produce most serious results in another.'

9. 2. Further discussion which took place at the 9th meeting of the Board held in 1938 showed that there was ample evidence that denudation was taking place on a large scale in India; the Imperial Council of Agricultural Research and the Forest Departments were fully aware of the situation, but no national concerted action to arrest the evil was either planned or in progress, although local efforts were being made on a small scale in the Punjab and United Provinces. This meeting finally adopted the following resolution: "This Board is convinced that the evils

of denudation in India are so serious and wide-spread that action for its further prevention should be taken without further delay. Denudation causes high floods in summer and low river levels and small supplies in winter, which result in:—

(i) damage to canal systems through interference with the regularity of canal supplies.

(ii) harmful deposits of sand.

(iii) interference with river navigation, and

(iv) wide-spread damage to the country-side.

Methods which have been found effective depend on the local conditions. They include—

(a) better field cultivation in order to reduce erosion from plough land,

(b) better live-stock management in order to reduce erosion from grazing lands,

(c) afforestation of such village waste land as can be devoted to the production of timber, fuel and fodder trees.

(d) the conservation of grass land,

(e) the substitution of organised *taungya* for shifting cultivation.

The Board considers that all Provincial and State Governments should be urged to develop and extend the most suitable local machinery to deal with further denudation and the above mentioned allied problems". Such a strongly worded resolution coming from a body of such high technical and administrative standing as the Central Board of Irrigation might have been expected to produce some tangible results, but apart from the subsequent appointment in 1945 of a strong Central Waterways and Inland Navigation Committee (now commonly shortened to "Quink"), the war period has effectively stopped all coordinated action on the larger Indian catchments.

9. 3. *Silt as a technical canal problem.*—As regards the silting of reservoirs the Research Committee of the Central Board of Irrigation, resolved that: The records from various parts of the world show that the silting of reservoirs may be serious or negligible. The committee consider that the factors determining silting vary from site to site and must therefore be studied locally. The committee recommended that—

"(a) Investigations regarding silt loads should go on *pari passu* with enquiries regarding water available for storage.

(b) The main source or sources of the silt load should be determined and steps should be taken so far as possible *before dam construction* to reduce erosion in the catchment area.

(c) Every opportunity should be taken to study silt accumulation in existing reservoirs with the object of obtaining information regarding the most economical design and method of construction with reference to the life of the reservoir.

(d) Samples of silt in suspension should be taken regularly at existing river gauging sites at or near any possible dam site. The clay content of the silt should be determined as this may exert an important influence on the volume of the deposited silt.

(e) Samples of deposits from reservoirs should be obtained so that an attempt may be made to estimate the volume of the deposited material with reference to its physical composition."

9. 4. To take examples from the established canals, in the Upper Jhelum Canal the canal capacity has been reduced considerably and silting has only been checked by installing silt-excluders in the canal bed. In the case of Lower Chenab Canal, excessive silt entry at the head has caused the bed of the main line to rise, and was giving great trouble in the branches and distributaries until expensive silt excluders were built in. On the Upper Bari Doab Canal the beds of branches and distributaries are consistently rising and heavy maintenance expenditure is incurred. On the Western Jumna Canal, no difficulty was experienced in the head reach, but the Main Branch silted to such an extent that its authorized supply could not be put into it without expensive raising of the Main Line. (F. F. Haigh in *Pb. Eng. Conf. Paper* 211).

9. 5. *Measurement of Stream-flow and Detritus Transported.*—Some knowledge of hydraulics is useful in the study of torrent behaviour to help us to estimate not only the maximum flood peak with which we may have to deal, but also the quantities of detritus which it may bring down from its catchment and deposit on the open bed which we are trying to reclaim. "Probably in no field of hydraulics have there been so many opposing views and even diametrically opposite statements concerning the behaviour of a river for varying flow conditions than are to be found in writings on river bed changes. This fact itself emphasises the complexity of the problem; no single rule may be set up concerning changes in the bed or regimen of a river"

says L. G. Straub, Professor of Hydraulics in the University of Minneapolis, and himself one of the foremost exponents of the mathematical approach to river behaviour. (1939 Liege meeting of International Association for Hydraulic Structures Research).

9. 6. This mathematical approach to the problem has been confined in India largely to canal behaviour and the designing of permanent channels, where the slope and cross-section are modified to obtain a balanced non-silting, non-eroding condition. Our problem in dealing with intermittent torrents which only flow occasionally and then carry enormous loads of sand and silt far out into the plains, is a very different one, and at the worst their capacity in exceptional storms for transporting detritus seems to be far in excess of what the laws of hydraulics would lead one to expect. The recorded silt load for peak floods in some of our larger rivers is alarming enough, but the capacity for damage by comparatively small torrents has to be experienced to be believed. (A knowledge of the actual load of sand per cusec of torrent at its recorded peak performance can however be obtained by sampling in the same way as the Irrigation Branch obtain their canal and river records, and we should try to build up a body of such data, along with actual measurements of the depth of sand accumulating in the torrent beds we are attempting to reclaim. For this latter, buried anchor posts marked in feet, such as are placed at dangerous road dips for the guidance of motorists, should be set up as a check upon our plane-table survey of the whole torrent bed.)

9. 7. The practical problem which confronts us in most reclamation projects below the hills is: For how many years can the stream be confined to its existing bed, on which it is annually depositing a given quantity of sand and thus raising the actual bed steadily higher than the level of the adjoining country? Most torrent beds are many times wider than they need be owing to this very reason of deposition. Our object is to canalise the torrent into a reasonably narrow channel and reclaim the rest, but in doing so it must be remembered that for a catchment area in bad condition our upstream engineering and afforestation will at the best be slow in reducing the future load of sand transported downstream. A fully canalised torrent can of course be expected to do some scouring of its own bed and thus make more room for its silt load within the bed itself, but the main lines of maintenance must be:—(i) to prevent islands building up round accidentally formed obstructions such as a newly seeded grass clump or a stranded tree trunk in mid-bed, and (ii) to maintain a wide belt of protective forest along the entire length of both banks, and to see that it is stocked not only with trees but with

well planned live-hedges of *nara-banha* and *kana* grass which will serve to comb out the silt load from any floods which may top the canalised banks. This wide belt forms an absorbtive "elastic-sided boot."

The two main exioms in hydraulics to remember are:

(i) the erosive or abrading power of a stream varies as the square of its velocity; if the velocity increases 10 times, its power to cut away and destroy its own bed and banks increases 100 times.

(ii) the transporting power of water varies as the sixth power of its velocity; if its pace increases 10 times its power to move detritus mixed with the water increases one million times.

In addition to the obvious sources of a river which are:—(a) surface drainage and (b) underground water storage discharged through springs and seepage, the hydrologists admit of a third class, (c) subsurface flow, due to the fractured condition of some rock formations which absorb the whole of light falls and prevent all surface run-off from rainfall of less than 1" per hour. (It is presumed that this phase is found on fairly steep slopes with little or no real soil but a surface of broken rock).

9. 8. *Classification of Detritus.*—As the description of material in torrent beds is often left vague, the following classification by sizes of the individual stone or sand-grain based on the diameter should be of use in ensuring a common standard of description.

Diameter in Millimetres	Inches	Suggested name.
2048—4096	80—160	Very large boulders.
1024—2048	40—80	Large boulders.
512—1024	20—40	Medium-sized boulders.
256—512	10—20	Small boulders.
128—256	5—10	Large cobbles.
64—128	2.5—5	Small cobbles.
32—64	1.3 — 2.5	Large pebbles.
16—32	0.6 — 1.3	Medium-sized pebbles.
8—16	0.3 — 0.6	Small pebbles.
4—8	0.16—0.3	Very small pebbles.
2—4	0.08—0.16	Extremely small pebbles (or perhaps granules or grit).

Diameter in Millimers.	Microns*	Suggested name.
1—2	1000—2000	Very coarse sand.
½—1	500—1000	Coarse sand.
¼—½	250— 500	Medium grained sand.
1/8—¼	125— 250	Fine sand.
1/16—1/8	63— 125	Very fine sand.
1/32—1/16	32— 64	Coarse silt.
1/64—1/32	16— 32	Medium grained silt.
1/128—1/64	8— 16	Fine silt.
1/256—1/128	4— 8	Very fine silt.
1/512—1/256	2— 4	Coarse clay.
1/1024 —1/512	1— 2	Medium grained clay.
1/2048—1/1024	0.5— 1	Fine clay.
1/4096—1/2048	0.25 —0.5	Very fine clay.

*A micron is one thousandth of a millimeter.

(Report on Committee of Sedimentation 1942, Nat. Res. Council Washington D.C.).

9. 9. Silt deposited in a torrent bed and completely dried out is of a very different physical character from the same material carried in suspension by the moving stream or held by stagnant water in a reservoir. Silty sand dried out in a torrent bed may have air spaces averaging 53% of its volume, and weight of dry material 77 lbs. per cft; for silty clay the figures may be 60% and 66 lb. per cft., whereas in reservoirs the same saturated sediments show 80% and 33 lb. per cft. (To keep fine sediment in suspension the velocity must be increased in proposition to increase in depth, otherwise the sediment is dumped on the bottom. On the other hand the movement of the bed load of detritus, with which a flowing stream continues to deepen its own bed by abrasion, is proportional to the volume of flow and to the slope or gradient of the channel. The proportion of sediment is usually greater on a rising stage than on a falling one, therefore as a flood reaches its peak it tends to do more digging of the stream bed than it can after the peak of the flood has subsided, as the lighter silt burden become less abrasive.) (*Proc. Amer. Soc. Civil Eng.*: B. J. Witzig, June 1943 and L. S. Hall, April 1944).

9. 10. *Flooded streams and silt transportation.*—Nearly a hundred years ago Everest calculated that the Ganges conveys more than 356,000,000 tons of sand and clay to the Bay of Bengal, an average of 900,000 tons a day. Many other Indian rivers are

more heavily silt laden than the Ganges. The Indus carries 1,000,000 tons a day when in flood. A stream in flood time accomplishes a hundred times the abrasive work it performs in normal seasons.

Irrigation engineers maintain that the annual silt yield of any river is a function of the catchment area (i.e., that it is more or less constant in annual total, irrespective of changes in rainfall or of plant cover) and that a study of a large number of rivers in India, U. S. A., Egypt, Europe, etc., shows this to be about 75 acre-feet of silt per 100 sq. miles of catchment. (A. N. Khosla in *C. B. Irrigation Proceedings* 1940.) This apparently leaves no room for factors such as deterioration of plant cover owing to over-grazing, disforestation, or other misuse; or in reverse a decrease in silt discharge which should be possible through afforestation. Nor does it allow for the exceptionally heavy storm which according to Kanitkar's field figures, breaks the annual average figure by many fold, so that the mathematical average may be far from the actual performance from year to year.

9. 11. Accurate observations of rivers at times of particularly high flood all agree upon the fact that the amount of debris carried may reach exceptionally high figures. For our large rivers, very high peak loads of silt have been recorded, as for instance in the Sutlej measured below the Bakhra Dam site:—

Discharge in cusecs.	Silt carried in acre per day.	Proportion of silt in water.
20,000	15	1 in 2,667
50,000	188	" 533
100,000	875	" 229
150,000	2,063	" 145

These loads of silt include very large admixtures of coarse sand and rubble, which of course are dumped in the river bed when the velocity of the stream decreases on the flat broad level portions of its bed in the plains. For these figures E. Vredenberg in his *Geological Report on the Bhakra* notes that out of the river's total catchment area of 18,554 square miles, the 1,000 square miles between Bhakra and Ropar contribute a very high run-off in August; this is the outer fringe of low foothills.

9. 12. The Uhl and Lambadug, which together provide the water supply for the Jogindernagar hydro-electric plant in

Kangra district, gave the following figures of silt carriage for a heavy two day storm on 24th|25th September, 1945:—

Date.	Discharge in cusecs.	Silt carried in thousands of cft. silt in 24 hours. Coarse.	Medium.	Fine.	Total.
The Uhl River.					
24th ...	429	12	11	c33	57
25th ...	1,529	42	32	111	186
26th ...	3,660	132	142	404	679
27th ...	1,247	...	...	...	...
The Lambadug River.					
24th ...	1,116	57	36	121	215
25th ...	3,516	175	168	557	901
26th ...	4,043	435	367	1,328	2,131

The average daily discharge for the two rivers for the whole of this month was 651 cusecs for the Uhl and 1,388 cusecs for the Lambadug. The total silt carried down by this one storm was 100 acre feet and consisted of 60% fine silt, representing frightful toll upon the 4,000 acres of farm lands of poorly terraced cultivation whence most of it came.

9. 13. In the case of smaller rivers or tributary streams before they join the main river, the silt content may be so heavy as to alter the character of the stream completely, making so rich a mixture that the stream runs with a smooth oily movement as of a thin cement mix, instead of the usual choppy rough surface which one associates with ordinary flood conditions. For instance, a Californian river, the San Juan, with a 24,000 square mile catchment and a run-off normally derived from melting snow fields, registered after torrential rains a peak of 13,000 cusecs which for a few hours carried a silt load of 75% of silt and sand and only 25% of water. A few hours later when the discharge had dropped to 5,000 cusecs the load was only 45% silt. (*U. S. Geol. Survey Water Supply Paper No.* 400, 1916. Measurements of Silt-laden Streams, by R. C. Pierce.) It is this peak load of solid material which changes the character of the stream and makes it capable of an immense amount of damage. Another Californian example of a smaller torrent is from San Bernardino with 2 comparable branch nalas, one with the scrub cover intact and the other with the plant cover destroyed by fire. Their run-off was 0.77 acre feet as compared with 2.82, or a ratio of 1 to 3.7, while the quantity of erosion debris was 4,000 cubic yards per square mile with plant cover as compared with 72,000 cubic yards per square mile from the nala without cover (Lowdermilk W. C. in *Journal of Forestry,* April, 1930). Comparable figures of spectacularly heavy silt load would be forthcoming from many of our smaller Punjab torrents if actual measurements could be produced. Any attempt to obtain measurements of flood peaks

and silt carriage by forest staff should be done with the advice of the Irrigation Branch officers who are specialists on this type of work, because the technique of obtaining true samples of the deeper layers of a river in flood is a difficult matter.

9. 14. *The Dynamics of Mud Flows and Debris-laden Streams.* —The enormous power for transporting heavy material which is sometimes shown by mud-flows has not previously been appreciated, and attempts of theorists e.g., the elaborate mathematical calculations given by the earlier European soil erosion writers such as Wang in Germany and Mathey in France, were based on the laws of water action and the presumption that streams could move stones and debris only in the ratio of the square of their velocity. Actually torrents are capable of doing far more once they get into a condition of turgid mud, and many examples of the transportation of enormous boulders weighing hundreds of tons being dumped miles from their natural position could be quoted, e.g., the single boulder in Dobi Orchard in the main Kulu valley; probably the one at the junction of the Beas and the Suketi at Mandi; the many huge rocks in the Arc valley in Haute Savoie; the frequently quoted and very well authenticated Parrish Creek in Utah.

The quantity of debris brought down by torrents may be so great as to remove the problem from the field of hydraulics to that of soil mechanics, because a flood in which the flow consists of 85% solid is more of the consistency of a sloppy concrete than a liquid and its powers for damage are immense. In Californian torrents a debris deposit of 100,000 cubic yards per square mile of catchment was reported for La Crescenta in 1934 from low hills somewhat similar to our Siwaliks where the scrub cover had been destroyed by fire just before the storm. (Figure 36.)

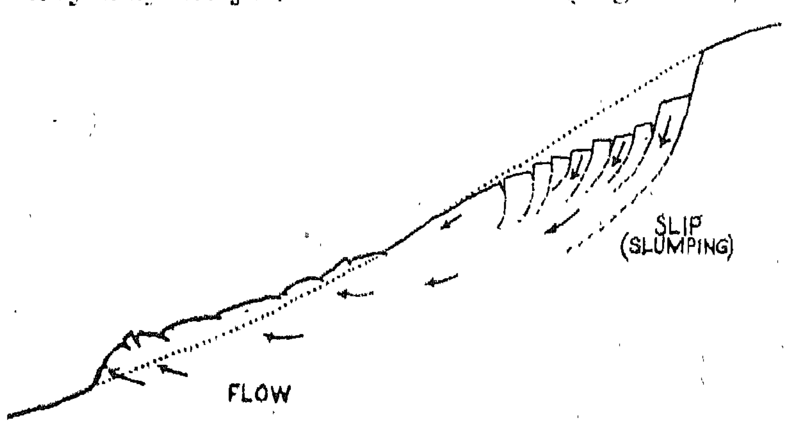


FIGURE 36

Longitudinal section through a typical hillside earthflow, showing the association of flowage in the lower part with slippage of slump type higher on the slope.

(H. H. Bennett's "Soil conservation" Fig. 97)
By courtesy of Mc Graw Hill Co.

PLATE 20 (i)

A torrent from the steep Wasatch mountains of Utah Parrish Canyon, destroyed crop lands valued up to §1,000 an acre in the 1930 floods, which brought these enormous boulders far out onto the plains below.

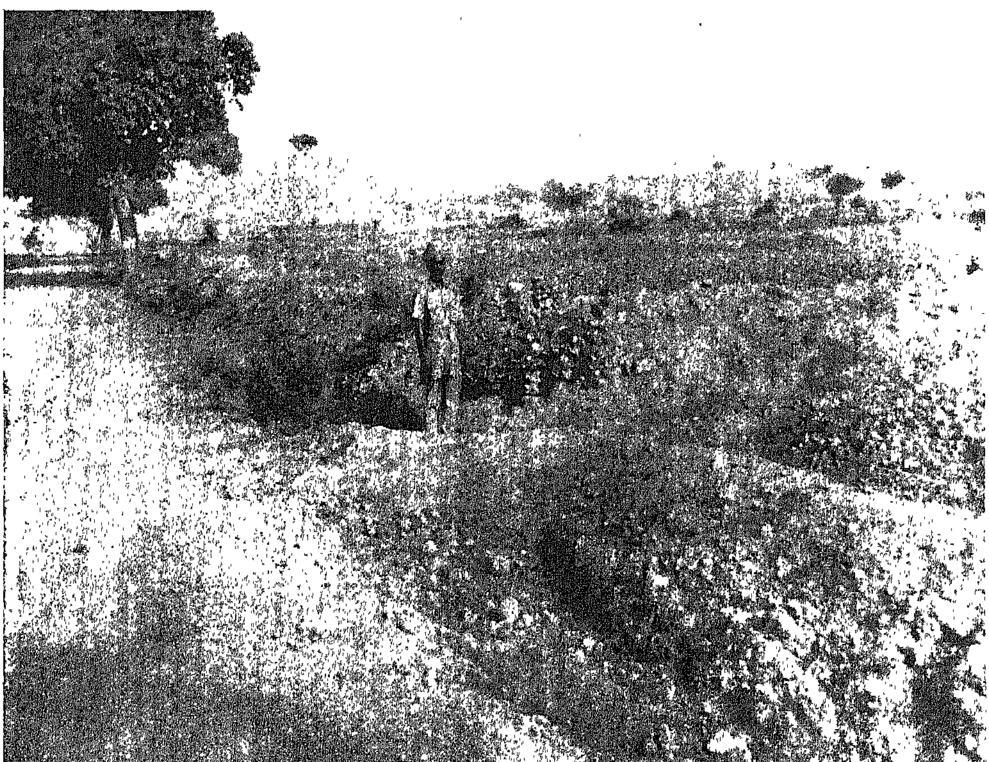


PLATE 20 (ii).

Diversion of water from a roadside drain into a field by means of a diversion bund which collects the road drainage & deflects it into the field. Jhelum Salt Range.—Para 13.28.

9. 15. An appreciation of the forces which have achieved such feats is reaching us through the study of water flow and "density currents" in the glass-sided models now commonly used in the various irrigation research institutes at Lahore, Khadakwasla near Poona, in Calcutta and Colombo. One fluid heavily loaded with debris does not readily dissolve into another fluid of comparatively clear water, so that a cushioning effect can be seen, which helps one to grasp how the heavy loads of silt held in suspension can be carried for long distances through a reservoir which is showing little sign of surface flow (Figure 37.) A better understanding of density currents will show how tremendous are the quantities of debris which can actually be transported by rivers once they get loaded up with concentrations of torrent action. Applying this new knowledge to our own torrents we begin to realise that once they are loaded with the fruits of sheet erosion and gullying during a heavy storm, it is not the water that moves the mud but the mud that moves the water.

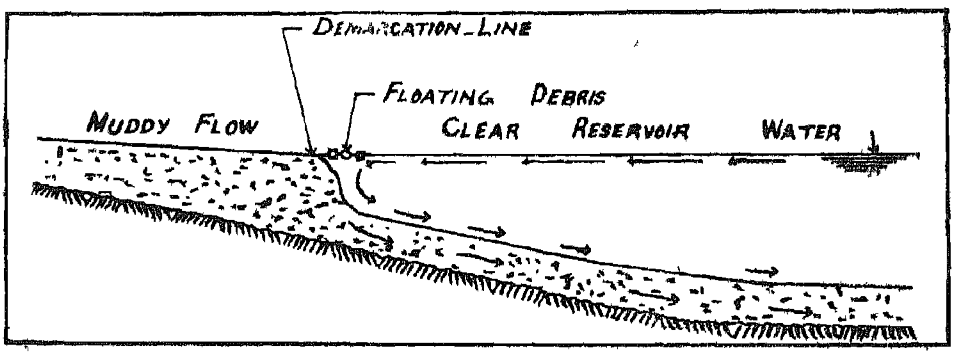


FIG. 37 SECTION OF RESERVOIR SHOWING BEGINNING OF UNDERFLOW.

In terms of down-stream sedimentation and the interference which a heavy load of detritus causes in major streams, upstream engineering is of major importance. Data and evidence from many sources all go to prove that soil conservation practices are more effective in reducing the amount of sediment carried than in reducing surface run-off; this is in fact its major contribution to flood control. It reduces the detrital load by reducing the production of waterborne solids at the source.

9. 16. *What happens to silt.*—Sedimentation behind our small check-dams and in the channels of contour terraces and behind watts may be rapid, and the accumulation of fine sediment may choke the pore space and so reduce seepage, but the damage done in this way to upstream and comparatively cheap and small works is infinitely less important that is the silting of major engineering works. Where there is an unobstructed channel, as in

most of our Punjab canal head-works, a heavy load of silt can be allowed to pass straight through, either down the river or out onto the fields, but where a high dam is planned to catch and hold up the entire flow, the amount of fine sediment carried becomes of major importance, because everything from boulders to the finest silt is dumped in the ponded bed, thus destroying the capacity for storage of water. In view of government's various high dam projects, the erosion intensity in the high hill catchments thus becomes of very vital importance.

In the case of the Siwalik torrents the sudden change from the confined bed in the hills to the broad flat bed on the plains causes an immediate dumping of the heavier particles within a few miles, and only the finer silt goes further down. This explains why the cultivators living at the down-stream extremity of the torrent flow welcome the silt-laden water and lead it onto their fields, while those nearer the base of the hills fear the deposit of coarse sand.

9. 17. Local accumulations of detritus are important factors in aggravating flood damage. They may be caused by (i) the main detrital fan building up just below the point of issue from the hills, (ii) deltas built up at the confluence of streams and tributaries, (iii) channel plugs or islands caused by sand gathering round some temporary obstruction such as a clump of grass or a tree trunk. Where the canalised course of the stream has been decided upon, every effort must be made to plough out or destroy such obstructions. The growth of an alluvial fan means of course that the actual stream bed is constantly being built up higher than the level of the adjoining land, and if it is very active it renders all attempts at permanent canalisation quite useless. When the stream divides and scatters into more than one channel as a result of such obstructions, the increased frictional resistance to flow in the poorly defined multiple channels entails that more and more material is being dumped within a short distance of the hills. The ratio of quantities dumped (i) in the main channel and (ii) carried out onto the adjoining land in time of heavy flood, determines the eventual cross-section of the flood-plane and the extent to which permanent canalisation is feasible.

9. 18. All the larger rivers of the Punjab and Sind have been slowly but steadily building up their beds. Thus the lowest excavations at Mohenjo Daro in Sind show that 5000 years ago that town was on ground 35 feet below the present ground level. It is estimated that the Indus bank levels have been rising since then at a rate exceeding 1 foot per 100 years (Sir C. C. Inglis:

"Denudation, Erosion & Floods", *Central Board of Irrigation Journal*, July, 1945).

On the other hand many head streams are cutting back at an alarming rate; for instance the loss of 50,000 acres of cultivated land in Jhelum district *between two revenue settlements* is very largely due to the tremendous power of local Salt Range torrents for cutting into the watershed ridge and reducing it to their own base bed level, the drop from main watershed ridge to near-by torrent bed being often 500 feet vertical in a mile of map distance.

9. 19. From data worked out by R. B. A. N. Khosla the maximum volume of silt accumulated in acre-feet per square mile varies roughly as $\frac{1}{A^{24}}$ i.e., the volume collected per square mile increases inversely as the catchment area and discharge, the maximum accumulation being of the order of 5.76 acre feet per square mile for a 10 square mile catchment, and only 0.63 acre feet per square mile for a 100,000 square mile catchment (*Ann. Rept. for* 1940-41 *of C. I. & H. R. S., Poona*).

9. 20. An actual survey of the flood-plane of the Kickapoo Valley, Wisconsin, where serious erosion of heavily grazed uplands has yielded a heavy load of detritus somewhat comparable with our Siwalik conditions and topography, though with only 400 feet drop from top to bottom of an 85 mile course and a catchment of 768 square miles, shows that the wide valley bottom is being built up with fresh silt at the rate of 1 foot every 20 years; the actual amount of new deposit being estimated at 31600 acre feet covering 12430 acres to an average depth of 2½ feet, the bulk of this having been deposited in 2 floods in 1935 and 1938. (*Effect* of Sedimentation of Floods *in the* Kickapoo *Valley*, Wisconsin by S. C. Stapp in *Journ. Geol.* 52 *No.* 1 of Jan. 1944).

We should try to collect similar data for Punjab conditions.

9. 21. The heaviest recorded load of silt for the Sutlej is 11 lbs. 9.6 oz. from 10 cft. of water, and this was divided into 2 lbs. 1.55 oz. coarser than 80 meshes to 1" and the rest finer silt. This load of debris is 1 in 54 by weight and 1 in 91 by volume of the water carrying it.

In the Sutlej the coarse silt ratio is constant until early August and then fluctuates in harmony with the total silt charge. Bad storms causing floods in the Sutlej are divided seasonally over 118 instances from 1884 to 1915:—

1 in February: 1 in May: 18 in June: 80 in July: 23 in Sept.
During August 1st-10th 53; 11th-20th 42; 21st-31st 23.

Thus storm incidence corresponds with heavy silt movement: in the hill catchments 3 or 4 moderately severe storms can be expected each year, but phenomenally high floods in Punjab rivers appear to occur at intervals of 12 to 15 years, notably in recent years 1924 and 1939 when widespread damage was done. Intensive local storms of cloud-burst intensity (3" of rain within the hour) occur irregularly, as in August 1944 in Kangra and September 1945 in Ambala.

Drought periods are less common. C. D. Abbot of the Smithsonian Institute showed from meteorological observations supported by tree ring study that drought cycles over a period of 400 years fall in cycles of 23, 46 and 92 years.

9. 22. *Examples of Storm Damage.*—Nurpur run-off plots in Kangra gave the following:—

In 1937 a 9.8" storm fell in 19 hrs. on 20|21 July and on a 1 in 4 slope the run-off from areas clipped of grass every alternate day to represent grazing was 95% of total rain, whereas from uncut grass and scrub cover it was only 20%.

Soil lost in lbs per acre was 20023 from the clipped plot as against 273 from the unclipped plot for this one storm. On the other hand the total losses from the clipped plots over a period of 21 months was 44175 lb. Thus nearly half the soil loss within this period was caused by this one storm. This agrees well with practical experience for it is realised that each phenomenally heavy storm is capable of starting a fresh cycle of erosion by establishing a complete new pattern of fresh gullies besides deepening the old ones to fresh depths.

9. 23. 3 *Methods of Run-off and Silt Calculations for Sohan Dun, Hoshiarpur District.*

(1) *From average silt carrying capacity of mountain streams in spate.*

Area 700 sq. miles.

Average run-off maximum intensity 500 cusecs per sq. mile; % of silt carried in heavy flood, 1|10 silt and sand, 9|10 water.

4 storms a year averaging flood intensity for 20" out of total of 40" rainfall lasting 20 hours fall and yielding 20 hours flood run-off.

$$\frac{700 \text{ sq. m.} \times 50 \text{ cu. ft. silt} \times 60 \times 60 \times 20 \text{ hours}}{50 \text{ cft. silt} = 1 \text{ ton.}}$$

= 5 million tons of silt.

(2) *From Nurpur Run-off Measurements.*

$1\frac{1}{2}$ tons of soil per acre lost in each 5" rain, 40" rain gives 12 tons of soil per acre per annum.

$700 \times 640 \times 12 = 5376000$ tons, say $5\frac{1}{2}$ million tons of silt.

(3) *From Buckley's Irrigation Statistics.*

Sohan Nadi (south only) Area 573 sq. m.
Recorded discharge 91000 cusecs.
Discharge in cusecs per sq. m. 159.
Total annual rainfall 40".
Length of catchment 50 miles.
Total period of flood discharge 80 hours.
Proportion of silt in water 1 in 100.
91000 cusecs × 80 hrs. $60 \times 60 \times \frac{1}{100}$ silt $\times \frac{1}{50}$ cft.

South nadi only	=5,200,000 tons.
Add North nadi 1|5th area	=1,050,000 tons.
Both North & South nadies	=6,250,000 tons of silt.

9. 24. *Stream-flow in Terms of Rainfall.*—The percentage of rainfall which emerges as stream-flow varies much according to climatic and geologic factors, and the condition of the plant cover can have only a limited effect upon the figure within a margin which is fixed primarily by these other factors. There is also a wide difference in the tropics between the annual figure of run-off to rainfall ratio and the same ratio for a single intense storm, the intensity of the fall being in itself a very important factor.

The average annual yield in run-off as a percentage of the rain falling in a catchment is known to vary between 30% and 100% for a great number of rivers in a variety of climates, and appears to be about 40 to 60% for most rivers in the temperate zone, but may be 20 to 90% for tropical conditions irrespective of what the total rainfall for the area may be. Some South Indian catchments with steep hills and a rocky soil give up to 75%, and the Himalayan rivers mostly give between 60 and 85%, vide A. N. Khosla's data, table 9.28. As examples of low yields two catchments of 200 and 300 acres in Malaya gave 23%, and for an area of 8300 sq. miles the Murrumbridgee in Australia gave only 20%, and the Kingwilliamstown in Cape Colony 105 sq. miles 21%. W. L. Strange in "Indian Storage Reservoirs with Earthen Dams" quotes a large number of tank catchments in Bombay and Madras as being below 30%.

9. 25. *Intensity of Rainfall.*—The worst storms only happen once in a century, or at the most every 20 to 30 years, and one has to choose between spending very large sums of money in making flood prevention works absolutely fool-proof against the problematical occurrence of such a storm, or spending less and taking a chance on this storm not occurring within the life of the project you are interested in. Every soil conservation worker should however have some idea of the possible worst that he should expect, so that many years of reclamation may not be blotted out in some major catastrophe before his reclamation has reached a more or less fool-proof stage. Flood control and soil conservation should both be based on intelligent anticipation of the maximum precipitation intensity, for the intensity of the rainfall has a considerable effect upon the percentage of run-off.

Figures for Northern India's best storms are:

Delhi 23" in 24 hours in Sept. 1876.

Lower Ganges Canal 80" in 4 days in Oct. 1884.

Others from elsewhere are:—

Deccan, India	9" per hour for 5 minutes.
Calcutta	12" in 3 hours, May 1835.
Madras	17" in 12 hours, Oct. 1846.
Rome	8" in 24 hours in Oct. 1922.
Columbus, Ohio,	5.6" per hour for 5 minutes.
Adelaide, Australia	5.6" per hour for 6 minutes.
Canepo, California,	11½" in 1 hr. August 1891.
Roumania	8" in 20 minutes = 24" per hr. August 1889.

For practical purposes, the maximum fall which may be expected for short periods in the Punjab is:—

5 mins. at 10" per hr.
10 mins. at 9" per hr.
15 mins. at 7" per hr.
1 hr. at 2.5" per hr.
6 hrs. at 2.0" per hr.

9. 26. Rain-gauges are of two kinds, (1) the ordinary receptacle whose contents are measured at the end of each storm or once a day by means of a measuring glass, and, (2) the intensity gauge which has some tip-tilting bucket device and a clockwork registration drum and needle by which it automatically records the rate at which the rain is actually falling into the receptacle. These latter are very expensive and so have not been installed anywhere in India except at the main meteorological observation

stations. To meet our needs in assessing erosion damage and stream-flow behaviour it is absolutely essential that we should now start collecting data on intensity of rainfall, as well as of total fall.

For our larger Himalayan catchments of 10,000 to 20,000 square miles with precipitation varying from heavy monsoon rains to a regime of winter snowfall and very little monsoon, it is essential also to obtain a more detailed picture of precipitation, and this can only be done by establishing a very large number of ordinary gauges wherever we can get local hill-men trained to take the reading for us. The question of snow gauging is also being taken up by the Irrigation Branch and the Meteorological Department.

As an example of the gaps in our knowledge which ought to be filled I can quote from an experience of some 20 years ago when, against the instructions of my conservator, I installed some rain-gauges in the Sutlej and for one station which had previously been shown in the 30" belt the first year's reading registered 112".

9. 27. *Condition of the Ground.*—W. L. Strange prepared a graph showing the marked difference in run-off for a given rainfall falling upon wet and dry ground, and this has been confirmed by many other workers since. Wet ground already has its *field moisture capacity* established throughout its depth and is therefore unable to absorb as much as dry ground can do; for storms of less than 1" there is unlikely to be any run-off from ground previously dry.

TABLE 9.28.

Hydrological data of some Himalayan catchments.

Name of river.	Catchment area at debouchment in plains sq. miles.	Area under glaciers sq. miles.	Percentage (3) of (2)	Maximum recorded flood (approx). cusecs.	Mean annual rainfall Inches.	Run-off in acre-feet.	Percentage Run-off of rainfall.	Minimum recorded discharge cusecs.	Minimum monthly discharge cusecs.
1	2	3	4	5	6	7	8	9	10
Indus	118,400	14,415	12.2	10,00,000	17.74	87,355,000	77.98	18,870	26,584
Brahmaputra	99,200	9,400	9.5	...	...	150,000,000	...	...	...
Jhelum	12,445	142	1.1	8,00,000	42.33	23,860,000	84.93	4,500	7,246
Chenab	11,399	1,475	13.0	7,50,000	47.24	23,277,000	81.06	3,884	6,830
Ravi	3,562	100	2.8	2,00,000	93,00	6,541,000	40.89	1,332	2,086
Beas	5,384	277	5.1	5,00,000	56.50	12,546,000	77.34	2,600	4,641
Sutlej	23,400	2,468	10.5	4,00,000	19.71	13,938,000	56.67	2,818	4,325
Jumna	4,470	131	2.9	4,00,000	73.00	8,296,000	47.90	2,459	4,242
Sarda	5,788	666	11.5	...	70.00	17,630,000	82.90	4,200	5,380
Kosi	23,808	2,228	9.4	7,00,000	60.00	40,600,000	60.00	7,000	10,000
Teesta	3,200	300	10.7	...	80.08	11,520,000	84.40	2,500	4,000

Copied from "Rainfall and Run-off" by Rai Bahadur A. N. Khosla.
(Annual Technical Report of Central Board of Irrigation 1942).
and Barlow and Meares' Hydroelectric Survey Report.

9. 29. *Hydrological Data for Some American Catchments.*

James.	Merrimack	Tennessee	Chattahoochee	
6,240 sq. m.	4,461 sq. m.	21,400 sq. m.	3,550 sq. m.	
41"	41"	50"	54"	Precipitation.
18%	24%	31%	19%	Surface run off as % of precipitation.
7"	10"	15"	12"	-ditto- as inches rain.
16"	20"	24"	22"	Total run-off. in inches rain.
25" (62%)	22" (53%)	26" (52%)	32" (62%).	Precipitation minus run-off in inches rain & %.
9" (46%)	10" (49%)	9" (35%)	10" (50%)	Ground water (percolated) run-off in inches rain, and as percentage of total run-off.

(Studies of Relations of Rainfall and Run-off for 4 rivers in U.S.A., U. S. Geol. Survey Water Supply Paper 772)

9. 30. *Catchment Run-off and Discharge Measurements.*—The measurement of the stream-flow of rivers and canals is a very specialised study, and many attempts have been made by engineers and others to produce formulae which will give an accurate estimate of the discharge of a given catchment area at times of peak floods, this being the limiting factor in the design of bridges, culverts, weirs, Irish bridges, etc.

9. 31. Run-off is usually expressed as a percentage of the rain which has fallen within a given catchment. Many formulae have been tried in the past, but the best up-to-date is that of Sir C. C. Inglis, lately Director of the Central Irrigation and Hydrodynamic Research Station at Poona:—$7000 \sqrt{A}$ when A is the area of the catchment in square miles. This is modified for small fanshaped catchments to read $Q = \frac{7000\,A}{\sqrt{A+4}}$

9. 32. The figures arrived at from the formula do not preclude higher actual flood peaks from such areas as the Naraingarh chos or the Pabbi torrents in Gujrat, as is shown by a Texas torrent which registered 1500 cusecs per square mile for a 400 square mile catchment, for which the Inglis formula gives only 350 cusecs per square mile. On the other hand Baluchistan

torrents seldom if ever reach the calculated maximum as the rain even in heavy storms is not sufficient to cause much flooding. Speaking generally the size of the catchment is the dominant factor, the maximum of flood varying approximately as $\sqrt{A}$. Annual rainfall is not an indicator of the maximum flood to be expected; catchments with low rainfall may show higher peaks than from a *ghat* catchment with 200" annual rainfall.

9. 33. Mr. T. G. Barlow, the first Chief Engineer Hydro-electricity for India, also working in the U.P., worked out a schedule based on the rough analysis of storms into:—

(a) to be omitted entirely—falls under 1" in 24 hrs. if no fall before or after.

(b) light falls; under 1½" in 24 hours, or under 1" if preceded by heavy rain.

(c) medium falls: 1½" to 3" a day or from 1" to 1½" when preceded or followed by other falls.

(d) heavy falls, over 3" or continuous falls of over 2" every day, also falls of an intensity of 2" an hour or over.

Barlow's table showing run-off assumed (as a percentage of rainfall).

	A	B	C	D	E
Light	1	3	5	10	15
Medium	10	15	20	25	33
Heavy	20	33	40	55	70

A = flat cultivated.
B = flat partly cultivated stiff soil.
C = average catchment.
D = hills and plains with little cultivation.
E = steep rocky hills.

As this Barlow formula is reported to give figures about 10% too low for the C. P. it is likely to be definitely low for Punjab foothills catchments.

9. 34. These formulae are merely given as an indication of what is to be expected, but there ought to be a great deal of more reliable data which the soil conservation staff are in a good position to produce. Every range officer should endeavour to get rain-guages established within the catchments he is responsible for, and should also establish discharge measurement points at which his guards can take measurements of the streams when in flood. The help of the Irrigation Branch can be obtained to lay down measurement points as sills in the smaller streams and teach the drill required for measuring.

9. 35. *Recorded Discharges of Rivers and Torrents.*—R. B. Buckley's *Irrigation Pocket Book,* 4th edition 1928, published by Spon, Ltd., 57 Haymarket London, S.W. I, contains much valuable information on rainfall, run-off, discharges, silting, evaporation etc., and designs for earth dams. The following figures of actual discharge which were measured where some of the Pabbi Hill torrents cross the Upper Jhelum canal, are copied from Buckley. The fall from the watershed is about 600 feet in 4 miles, the average slope being about 1 in 100. Rainfalls of 5 to 6 inches in 24 hours are common and even 9 inches in 24 hours has been recorded, although the annual average is only about 22". The maximum discharge as shown only endures for a short time, but the cross drains on the canal provide for 2400 cusecs per square mile. Torrents are spaced ½ to 1 mile apart.

Name of Torrent	Catchment area sq. miles.	Recorded discharge in cuses	
		Total.	Per sq. mile.
Suketar No. 1	175.00	110 429	631
Suketar No. 2	48.54	62,612	1290
Jaba	56.00	56,000	906
Kasba	5.67	5,676	1001
Mehi	9.15	16,244	1775
Fatehpur	2.10	4,510	2148
Roza	1.47	6,520	4435
Puran	0.99	3,372	3406
Changas	0.79	4,056	5134

It will be seen from these data that the smaller catchments show the greatest peak discharge per square mile, but the bigger torrents of upto 50 and even 100 square miles in area hold the *greatest potential danger* to the canal which they cross.

9. 36. R. E. Purvis reported for one of the Upper Jhelum canal torrents a discharge of 4165 cusecs per square mile for a catchment of .88 sq. m. (run-off at rate of 6.5" per hour) and for a catchment 1.24 sq. m. a discharge of 4607 cusecs|sq. m. The Jaba torrent which crosses the Upper Jhelum canal has a catchment of 56 sq. miles, 13 miles long, and has registered a velocity 6 ft. sec. for a period of 4 hours for a rainfall of 1.7" per hr.: supposing it had all run off, 1097 cusecs.|sq. mile is thus calculated, but the largest observed was 906 cusecs.|sq. mile.

Other recorded flood discharges:—

	sq. m.	cusec/sq. m.
Gujrat district, Punjab	48	1312
" " "	56	1000
" " "	174	550
Mexico	544	590
Kalinadi	2593	51
Madras	2100	82
"	7000	23
"	10000	18

9. 37. For larger catchments the run-off per unit area is less but the total may be huge, for instance one flood on the Karamnasa River in Mirzapur district was measured at two localities. For a catchment of 200 square miles the flood peak was 84777 cusecs and at a lower place where it was 345 sq. miles the peak was 126000 cusecs. No rainfall figures were quoted. (A.R.B. Edgecombe in *C.B.I. Journal, Jan.* 1945).

Strange's estimate of maximum run-off for catchments upto 5 sq. miles in Bombay was 2 inches per hour, giving 2 cusecs per acre, but the peak run-off for our smaller Pabbi catchments yields higher figures. So for badly ravined land 2½ cusecs per acre should be the figure used for large catchments and with a maximum of 8 cusecs for small and completely ravined catchments, vide table 9. 42.

9. 38. To measure stream-flow, select a straight stretch without pools, and peg out a convenient length of uniform width. Measure the width of the stream and find '*average*' depth by sounding at intervals across it. Time the passage of a stick or float, repeating 4 or 5 times. Length of run in feet divided by average time in seconds gives surface velocity.

$$\text{Cross section of area in square ft.} \times \frac{\text{surface velocity in ft. per second}}{2}$$
$$= \text{discharge in cusecs.}$$

9. 39. *Run-off Estimates by Rule of Thumb.*—The most reliable method of estimating the discharge at any given point is by measuring the cross-section of the stream bed and the velocity of the flood by actual observation at a time of high flood. From the actual discharge thus obtained, the size of the outlet to be provided can be taken from the table 9.39A.

Table 9. 39A. *Approximate Discharge Capacity in Cubic Feet per second of Rectangular Notches in small Check Dams and Field Outlets.*

Depth of notch D, feet.		Spillway length, L, in feet required for various discharges indicated.											
		2	4	6	8	10	12	14	16	18	20	22	24
0.5	Cubic feet discharge per second	2.3	4.5	6.8	9.1	11.3	13.6	15.8	18.1	20.4	22.6	24.9	27.2
1.0		6.4	12.8	19.2	25.6	32.0	38.4	44.8	52.2	57.6	64.0	70.4	76.8
1.5		11 8	23.5	35.2	47.0	58.0	70.5	82.3	94.1	105.8	117.6	129.3	141.1
2.0		18.1	36.2	54.3	72.4	90.5	108.6	126.7	144.8	162.9	181.0	199.1	217.2
2.5		25.3	50.6	75.9	101.2	126.5	151.8	177.1	202.4	227.7	253.0	278.3	303.6
3.0		33.3	66.5	99.8	133.0	166.3	199.5	232.8	266.0	299.3	332.5	365.8	399.1
3.5		41.9	83.8	125.7	167.6	209.5	251.4	293.4	335.3	377.2	419.1	461.0	502.9
4.0		51.2	102.4	153.6	204.8	256.0	307.2	358.4	409.6	460.8	512.0	563.2	614.4
4.5		61.1	122.2	183.3	244.4	305.5	366.6	426.7	488.8	549.8	610.9	672.0	733.1
5.0		71.6	143.1	214.7	286.2	357.8	429.3	500.9	572.4	644.0	715.5	787.1	858.6
6.0		94	188	282	376	470	564	659	752	847	941	1035	1130
7.0		118	237	355	474	592	711	830	948	1067	1185	1304	1422
8.0		144	290	435	560	724	870	1014	1160	1304	1450	1594	1738

Computed by formulae $Q = 3.2\ L\ H^{\frac{3}{2}}$.

where Q = discharge in cubic feet per second.

L = length of spillway in feet across the base of the notch.

H = head of water on crest of spillway in feet.

(Extracted from cyclostyled "Watershed Handbook of U. S. Forest Service Region 3, 1934).

A rough rule of thumb derived from the above table is:—

for ½ ft. depth of water the discharge in cusecs=width of sill in feet.

for 1 ft. depth of water the discharge in cusecs = width of sill × 3.

for 1½ ft. depth of water the discharge in cusecs=width of sill × 5.

for 2 ft. depth of water the discharge in cusecs = width of sill × 9.

9. 40. In the absence of such measurement various formulae can be used, but very few of these take into consideration all the factors governing streamflow which can be summarised thus:—

1. extent, duration, and intensity of rainfall.
2. the paths of storms.
3. any natural or artificial storage for peak floods along the stream.
4. the size, shape, and gradient of the catchment area.
5. character of ground and of plant cover.
6. relative time taken for run-off to reach site from all points of perimeter.

The M.E.S. formula for the N.W.F.P. is:—

Q = maximum discharge in cusecs.

M= area of catchment in square miles above site.

For M of less than 9½ sq. miles Q=1200 M3|4.

For M of 9½ to 12000 sq. miles Q=2100 M1|2.

This can be checked by reference to the Dun Drainage Table, (table 9. 41) in which the choice of the correct percentage column depends upon local experience, the 120% being for bare stony hills, the 100% for hills with normal plant cover, 80% for foot-hills or plains close to hills, and 50% for plains only.

Thus for a catchment of 10 acres of terraced fields, using the 80% column, your field outlet requires a cross-section of 2½ sq. ft. which can be made either 5 ft. width and 6 inches depth or 2½ ft. width with a 1 foot depth. Or for a catchment of ravined land of 90 acres, using the 120% column the cross-section required is 30 sq. ft. which could be provided in a 20 ft. sill with 1½' ft. depth, or a 15 ft. sill to pass a 2 ft. depth.

9. 41. *Waterway Cross-section Area for given Catchment Areas.* (*"Dun Drainage Table"*).

Catchment Area		Cross-section in sq. ft.			
in sq. miles.	in acres.	120%	100%	80%	50%
.01	6.4	2.4	2.0	1.6	1.0
.02	12.8	4.8	4.0	3.2	2.0
.04	25.6	9.0	7.5	6.0	3.8
.06	38.4	12.6	10.5	8.4	5.3
.08	50	16.2	13.5	10.8	6.8

Catchment Area		Cross-section in sq. ft.			
in. sq. miles.	in acres	120%	100%	80%	50%
.10	64	19	16	13	8
2.0	128	38	32	26	16
.30	192	53	44	35	22
.40	256	67	56	45	28
.50	320	79	66	53	33
.60	384	89	74	59	37
.80	512	106	88	70	44
1	640	120	100	80	50
2	1280	240	200	160	100
3	1920	360	300	240	150
4	2560	466	388	310	194
5	3200	546	455	364	228
10	6400	815	679	543	340
20	12800	1164	970	776	485
30	19200	1516	1080	944	590
40	25600	1620	1350	1080	675
50	32000	1812	1510	1208	755
100	64000	2544	2120	1696	1060
200	128000	3564	2970	2376	1485
1000	640000	7656	6380	5104	3190

(Extracted from Table VIII of M.E.S. Handbook Sixth Edition 1931. Vol. III Roads).

9. 42. *Normal Monsoon Storm Intensity Run-off* (in cusecs).

Catchment Area in acres.	3	5	10	20	50	100	150	200	640
Rice fields...	1	1½	3	5	10	18	25	32	60
Scrub forest check dammed ; fields completely watted.	4½	7	14	25	50	92	130	160	300
Scrub forest closed to grazing; ... fields incompletely watted ...	9	15	30	50	100	185	250	320	620
Scrub forest open to grazing; ... fields neither terraced nor watted	16	26	50	84	180	315	440	560	1040
Ravined land	24	40	80	130	300	500	700	900	1600

9. 43. The above schedule is a very arbitrary set of figures which can be safely employed in calculating the size of apertures for outlets and spillways, using one of the various formulae in which Q = the maximum discharge in cusecs for which the design will provide, e.g., that recommended for use with the Missouri Spillway (para. 6.37) is as follows:—

For calculating the capacity of a spillway

$$Q = 3.85\ B\ H^{\frac{3}{2}}$$

Where Q = the designed maximum discharge in cusecs.
B = width at crest level in ft.
H = upstream head over crest in ft.

9. 44. *Shape of Catchment Area.*—The shape of a river's catchment and the fall from the perimeter to the stream-bed have a major effect upon the flood curve for the catchment. Many formulae have been proposed which make an attempt to cater for this, but they are either so empirical as to be of little practical value, or else their accuracy depends upon the user's skill in choosing the correct values for the various variable factors, as expressed in a co-efficient. Possibly the best is R. H. Rhind's, vide Buckley's "Irrigation Works of India":—

$$D = \frac{C \times f \times R \times M}{L}$$

D = maximum discharge in cusecs.
C=a coefficient, the value of which varies inversely as some power of fraction $\frac{R}{L}$ as listed below.
f = average fall in feet per mile in 3 miles of bed.
R = greatest average annual rainfall in inches.
M = area drained in sq. miles.
p = variable index, varying inversely with some power of M.
L = greatest length of basin in miles.

Examples showing how coefficient C has been chosen:—

Rivers.	Area (M)	Recorded discharge in cusecs (D)	Discharge in cusecs per sq. m.	Greatest average rainfall.	Length (L)	p.	C
Tansa Bombay ...	52.5	35000	666	101	9	2.328	0.0123
Adeela ...	141	37000	262	29	11.9	2.179	0.0717
Julianee ...	360	17758	49	39	60	2.047	0.14
Sohan, (Hoshiarpur) ...	573	91000	159	123*	27	1.987	0.036

NOTE* The figure of 123* relates to Dharamsala and appears to have been wrongly applied to the Sohan, whose average rainfall is certainly not more than 40 for the Sohan Dun & 80 for the Kutlehr hills in which many of its feeders rise.

9. 45. Apart from formulae with coefficients which need accurate local knowledge to guess correctly, Buckley gives a series of straightforward mathematical calculations to show how any factor which delays the run-off over a period of time serves to flatten out the peak floods. This is of such importance in our soil conservation technique as supporting the value of any investment made in gully plugging or ponding back of side streams that I have no hesitation in quoting the data from Buckley:—

Effect of Time Lag on Flow off a Catchment Area.

Rainfall in inches	cft. per sq. m.	Acre-ft. per sq. m.	Discharge from Catchment in 1 hr cusecs	1 day cusecs	1 week in cusecs	acre-ft per day per. sq. m.	1 month cusecs.
½	161,600	26.6	322.6	13.4	1.9	3.8	0.5
1	2,323,200	53.3	645.3	26.8	3.8	7.6	0.9
5	11,616,000	266.6	3226.6	134.4	19.2	38.1	4.5
10	23,232,000	533.3	6453.3	268.8	38.4	76.2	8.9

9. 46. For comparing the relative values of steep and gentle topography the following figures may be of value:—

Ratio of run-off to total rainfall: steep rocky hills .7 to .9.
ordinary hills .5 to .7.
undulating land .35 to .5.
flat land .2 to .35.

9. 47. *Run-off Data—Miscellaneous Facts and Figures.*

Discharge of 1 cusec continuous per sq. mile = total discharge of 13.56″ annual rainfall from 1 sq. mile of catchment, presuming there is no loss en route.

Strange in "Indian Storage Reservoirs" gives 200 sq. miles as the maximum for any sudden rise in run-off per sq. mile, any catchment larger than this being reduced by various factors to a steady average discharge.

10 lb. water = 1 gallon = 277 cubic inches = .160 cu. ft.

1 cft. water=62¼ lbs.=6¼ gallons.

Trenches: 25 cft.—(Jaijon trench type) = 1572 lbs. water or 156 gallons.

Trenches Afforestation 10′ × 1′ × 1′ = 625 lbs. or 62 gallons.

1 cft. per sec. per day gives 2 acre-ft. = 86400 cft.

1 cft. per sec. per year = 31,536,000 cft.

Theoretically 1 inch run-off from an acre in 1 hr. gives 1 cft. per sec. or in other words cusecs per acre is the same as inches per hour. 1″ rainfall thus = 640 cusecs per sq. mile. Hence 3″ rain per hour gives 1920 cusecs per sq. mile and 6″ gives 3840 cusecs.

Chapter X.

CANALISATION OF SMALLER TORRENTS.

10. 1. *Stream-bank protection.*—In certain types of deeply eroded plateaux the steep banks of streams are in a crucial state and special precautions ought to be taken to protect them. J. B. Clements has emphasised this in the case of Nyasaland ("Land Use in Nyasaland." *Imp. For. Inst. Paper No.* 9). In Java the district of Bali has steep ravine banks which have been brought under a protective law in 1936 to prevent clearing of steep banks except for the cultivation of bamboos, palms and other perennial crops of known value as a thick cover. There, as in many parts of the Punjab, the ordinary protected forests demarcated in blocks are not in themselves sufficient to protect the fields, and demarcation is needed of the long, narrow strips of jungle which should clothe the ravines. Where this cover has been destroyed, gullies eat rapidly into the adjoining plateau lands, and these are soon rendered physiologically arid through the destruction of the local water-table which falls to the level of the nearest gully bottom.

10. 2. Another type of torrent conservation is where good farmland has been swamped with sand or rendered unstable by the outflow of a torrent over the more level stretches in its lower course. Given some improvement in the run-off conditions upstream, much of the land now lying waste can be rejuvenated by stream training. This generally must aim at confining the stream to a more clearly marked bed by means of a screen of plant growth or low bunds built parallel to the stream and the afforestation of the reclaimed land with any tree and bush species which will flourish in the sand. Every country appears to have its own peculiar set of plants which qualify for this work. The stream must not be confined too closely to start with, and it is only by a process of trial and error that new banks can gradually be rebuilt nearer each other as a wider strip is reclaimed and the stream ceases to break out. Some years later when the regime of the stream has been more or less stabilised by these forest strips and by the conservation upstream, the less vulnerable parts of the strips can be cleared for cultivation and should yield good field crops, but the process of disforestation must be carefully controlled. There is a sound financial future for such efforts, and they would be a fine contribution to economic

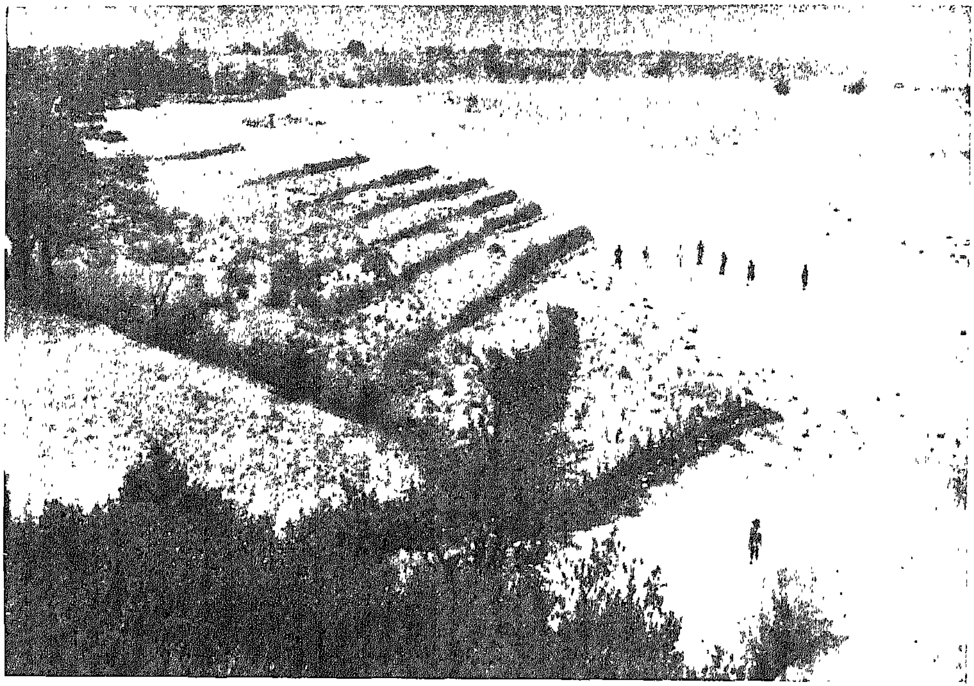


PLATE 28. (i)

Amb cho reclamation in Hoshiarpur Una tahsil showing how land has been raised by silting in the ea of each live hedge & is filling up naturally with kahi grass.—Para 10.4.

PLATE 28. (ii)

Grabbing land back from a torrent which has been partially tamed Hedges of *nara* twigs are buried in a trench to catch silt & so raise the level of the ground being reclaimed. Dholbaha Cho, Hoshiarpur. The silt is deposited behind such hedges, not in front of them.

and social stability in many areas which are now on the downgrade because of uncontrolled torrent and river action. In this respect there is a striking similarity in climate, topography and destructive torrent action in many areas of the dry sub-tropics such as North China, Palestine, the Punjab, the Wasatch Hills of Utah, and the citrus fruit districts of Southern California.

10. 3. The reclamation of torrent-ruined land which can be made productive again by a simple type of afforestation is the responsibility of the community rather than the individual, for if it is to be successful and permanent it requires to be done throughout the length of the torrent bed and not just at a few places, and the shelter-belt must be maintained throughout.

10. 4. The method is simply to check the flow of floods gradually by confining them to a slightly narrower bed by means of "herring bone" plantations of sand loving plants such as *nara* (*Arundo donax*) and *banha* (*Vitex negundo*) set at a slight angle to the torrent's direction. Behind this outer defence *kana* grass (*Saccharum munja*) is planted fairly thickly in the sand. The effect is to persuade the floods to deposit part of their load of fine silt there and thus raise a new platform. If the edges of this are kept fully protected with a dense belt of every type of tree, grass and shrub which will succeed locally, the remainder can be planted up with *sissoo* or sown with *khair* or *babul* and so made fully productive with tree growth as well as a defence for the fields behind.

10. 5. *Choice of plants for torrent reclamation.*—The plants selected will vary from district to district and it is important to know past local experience. The mainstays throughout the province are *banha* (*Vitex negundo*) also called *marwan* in Attock, and *nara* reed (*Arundo donax*) but there are many places in which one or the other has not been introduced and where defects of local supply must be overcome by diligent propagation of planting stock. *Banha* will root readily from branches stuck in the ground, but one or both ends should reach the surface, whereas with *nara* reed long lengths of cane can be buried completely either in a burdle laid in a trench, or with single nodes or roots transplanted at close interval. In the case of *kana* grass (*Saccharum munja*) which is almost universally available, the root portion should not be buried too deep, for when swamped with loose sand it is apt to die off. The most successful introduction economically has so far been *bhabbar* grass (*Eulaliopsis binata*) but the extent to which this can be extended into the western half of the province has not yet been determined and much further work is required on this point; in the eastern districts it prefers fairly steep slopes and will seldom do well in nala

beds, but this need not necessarily hold good in the more westerly districts (see para. 4.21m). As *bhabbar* seed has low viability it is best propagated by transplanting "sets" which are obtained by digging up a clump and splitting this into portions the thickness of one's thumb, taking care to preserve the few long roots intact. *Kahi* grass (*Saccharum spontaneum*) usually comes in so readily and naturally on torrent beds when these are protected from grazing that planting is seldom justified.

10. 6. The provision of stump cuttings of sissoo (*Dalbergia sissoo*) has been difficult in the past owing to the heavy expenditure involved in establishing isolated nurseries with well irrigation; future supplies on a much bigger scale will be forthcoming from our canal avenue nurseries in the Fuel Circle, but each soil conservation district should aim at being independent, so far as possible, because dependence upon outside supplies has hindered the circle's planting and torrent reclamation progress. In transplanting both *bhabbar* and *sissoo* stumps the root portion of the transplant should be dipped in liquid mud as soon as it has been prepared for planting; this will keep it moist and protect it from excessive evaporation while exposed to the air.

10. 7. In the selection of posts and uprights for brushwood check-dams and spurs, species which are likely to take root as driven posts or as large planted poles should be favoured, e.g. *kambal* or *jhingan* (*Lannea grandis*), *Bombax, Ficus cunia, Ficus bengalensis, Ficus religiosa, farash* (*Tamarix indica*) and *sissoo* itself.

10. 8. For planting in the immediate neighbourhood of check-dams with the primary object of consolidating the newly collected silt, a considerable number of species can be used, but various local types of *keora* (*Agave spp*) should be given preference, avoiding those with soft and droopy outer leaves. The *keora* cut leaves can be used as a source of both fibre and pulp fodder, but a cottage industry method of separating and using both of these has still to be worked out and an industry built up. Results with prickly pear of various sorts have been almost invariably disappointing; except as a hedge to keep cattle out of fields, it is of only limited use in sand reclamation.

10. 9. Great use in the past has been made of *walaiti ak* (*Ipomea carnea*) particularly in Gurdaspur and Amritsar districts as a tree guard and for revetting stream banks, but this is not an ideal plant for the purpose as it does not form thickets unless constantly replanted, nor is it of any particular use other than for twisting into hedges on the boundaries of fields. Where it is prolific it is useful in small nala beds for slowing down the

current, but in the drier districts it is apt to remain as a single stalk instead of forming a clump and is only an inferior fuel.

10. 10. In the past work we have not made sufficient use of the 4 available bamboos namely:—

Dendrocalamus strictus—bans, male or solid bamboo.

Bambusa nutans—nal.

Bambusa arundinacea—maggar.

Dendrocalamus hamiltonii—mohr.

The propagation of all of these must be followed up energetically wherever there is any prospect of success. (The solid bamboo (*bans*) is an ideal plant for establishing on check-dams and along raised banks of canalised streams) but so far its planting has been done more upon stony slopes where it takes many years to establish itself. Large scale nursery provision must be made for growing *bans* seedlings, as in most districts it takes 3 years to produce a good transplant. When transplanting bamboo rhizomes it is important to ensure that each piece of root contains at least one undamaged bud.

10. 11. *Live hedges to catch silt.*—Our ultimate aim is the gradual canalisation of every wide torrent bed so that average floods can be confined to one definite channel and worst floods can discharge their peak by overflowing into prepared spreading beds in low ground near by. The first step towards this is to reclaim as much as possible of the dry sandy bed. Starting from each bank and working out into the middle a herring bone pattern of live hedges is laid down in such a way that a single portion forms more than a 30 degree angle to the direction of the stream, see diagram 39, and plate No. 21. The object of these hedges is not to stop the water but to allow it plenty scope for slowing down, thus forcing it to deposit a larger proportion of its load of silt. This raises the level of the ground in rear of and down-stream from these hedges. Hedges can best be made by digging a 2 foot deep trench, bending 6 foot lengths of *bana* and *nara* into the bottom of its trench, filling in damp sand on top and trampling the whole firmly down. The best season for doing this is immediately after the winter rains, when the moisture in the sand will allow roots to form and thus stabilise the hedge as a live and rooted one which has good prospects of surviving the summer drought and then the onslaught of the monsoon floods. Live hedges will of course take root if planted during the monsoon but they obviously will not be as sturdy to withstand floods, so monsoon planting should only be done on sites which are not exposed to direct torrent action.

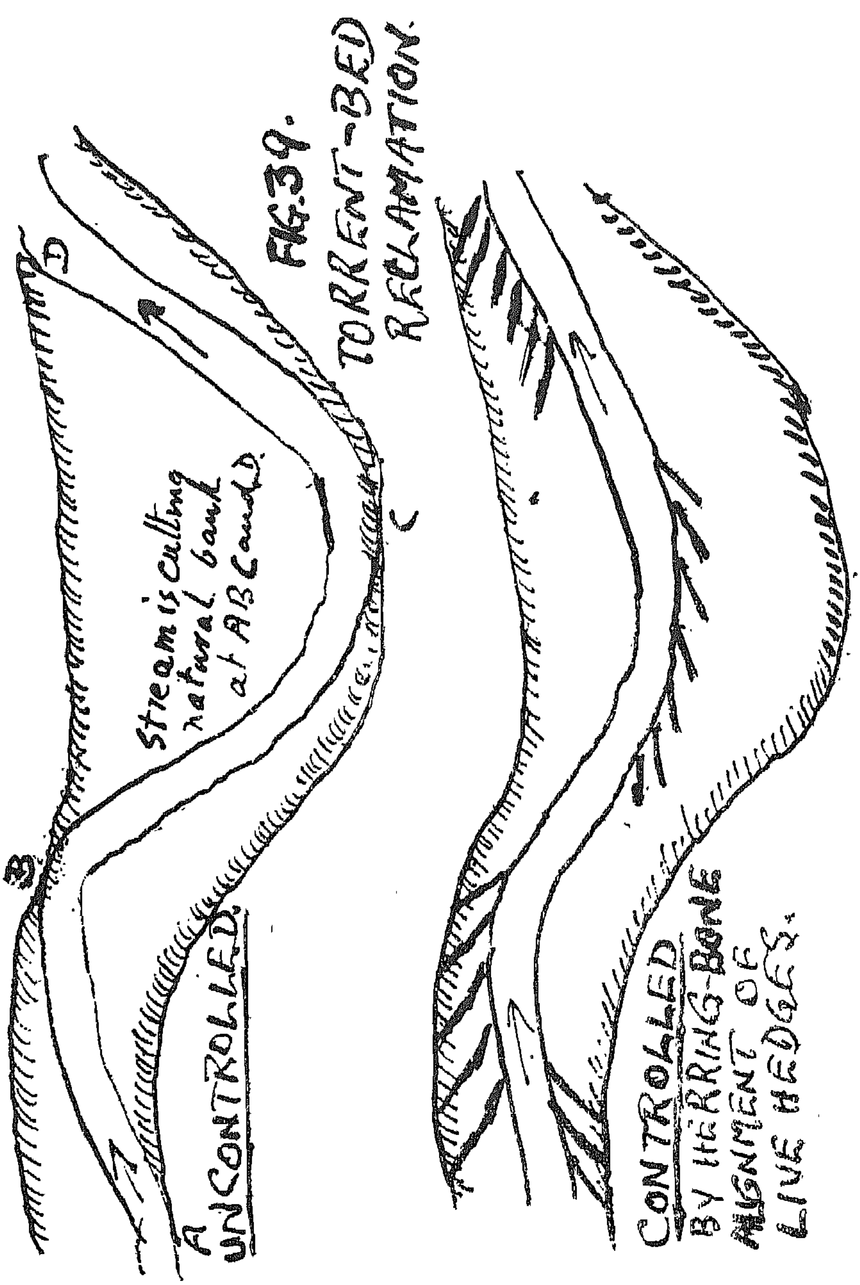


FIG. 39. TORRENT-BED RECLAMATION.

10. 12. *Layout of Stream-training.*—Starting where the torrent has left wide bays of sand, a series of live hedges of brushwood and stakes are buried in trenches set at an angle of 25—30 degrees with the current. The material to be used is any species which will root readily in damp sand, preferably in a mixture of species. Lengths of twig sticking up to form a fine-tooth comb delay the silt-laden flood and persuade it to dump some of its load of grit. Two parallel rows 2 ft. apart of closely spaced *banha* and *nara* laid at only a slight angle to the torrent, say 10—15 degrees, will often establish long lengths of natural bank along the flood edge as the sand is deposited in the space between the two rows.

10. 13. At crucial points where torrent action is strong this type of live hedge network has to be supplemented with a little armour-plating in the shape of regular spurs of driven posts between which is strapped a wall of cut brushwood anchored down by boulders, and in extreme cases with wire-bound bolsters filled with rocks.

10. 14. From the rules enunciated on the meandering of streams (para. 11. 11) it is obvious that a series of sweeping curves is more likely to accommodate the stream rather than a dead straight course, but obviously sudden sharp bends are to be avoided. Local experience with each type of torrent will soon show what is the optimum spacing and arc of curves. Once the course has been determined upon, all odd clumps of grass taking root in this channel should be ploughed out.

10. 15. The next stage is shared by nature and ourselves. Nature usually provides a mat of creeping *kahi* (*Saccharum spontaneum*) on all such sand as soon as it is protected from grazing. We supplement this by transplanting clumps of *kana* (the tall cane grass *Saccharum munja*), and in the lea of each clump we plant a *sissoo* stump. Where the sand contains good silt the *sissoo* starts height growth at once and in a matter of 4 years will have caught up and suppressed the *kana*, but where the bed is pure sand and the water-table level drops to more than 6-8 feet in the dry periods, the *sissoo* hangs fire and may die back year after year and may eventually have to be replaced by *khair* (*Acacia catechu*), *mesquite* (*Prosopis juliflora*) *phulai* (*Acacia modesta*), or *kikar* (*Acacia arabica*) in the more intractable patches. Speaking generally however *sissoo* is king and will give a harvest of fuel in 6-8 years from thinnings and of small saw logs and crooked poles in 20 years and of really good saw logs in 30. The *kahi* and *kana* grasses and later other fodder

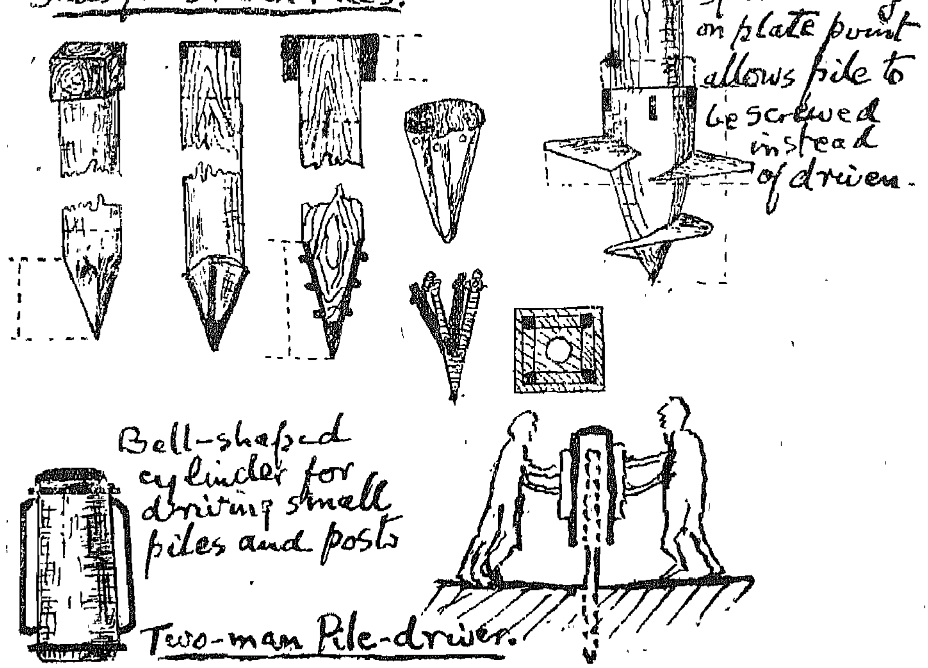
grasses and in some cases *bhabbar* grass for paper making all give interim cash returns.

10. 16. *Spurs.*—The heads of spurs must be well built into the natural bank of the stream and placed at a down-stream angle of not more than 30° to the current, so that a stilling pool effect is produced and silt thus encouraged to deposit behind and down-stream. Intervals can only be learnt from experience but as a rough rule where the main current is parallel to the bank, spurs 100 ft. long at an angle of 30° should be 150 ft. apart. Where the stream is to be deflected beyond some obligatory point such as a bridge or a natural high bank, it is best to start straight off with a very short spur and use a gradually lengthening series beyond, rather than site a larger obstruction lower downstream.

10. 17. The driving of posts must be thoroughly supervised because scamped work at this stage means failure later. Various types of derrick and "monkey" have been tried for driving the post of dropping a weight on its head, but none are fully satisfactory and further experiment is needed in this work. The *Military Manual of Field Engineering* should be consulted and local equipment improved along orthodox engineering lines. Figure 40.

Figure 40

Shoes for Driven Piles.



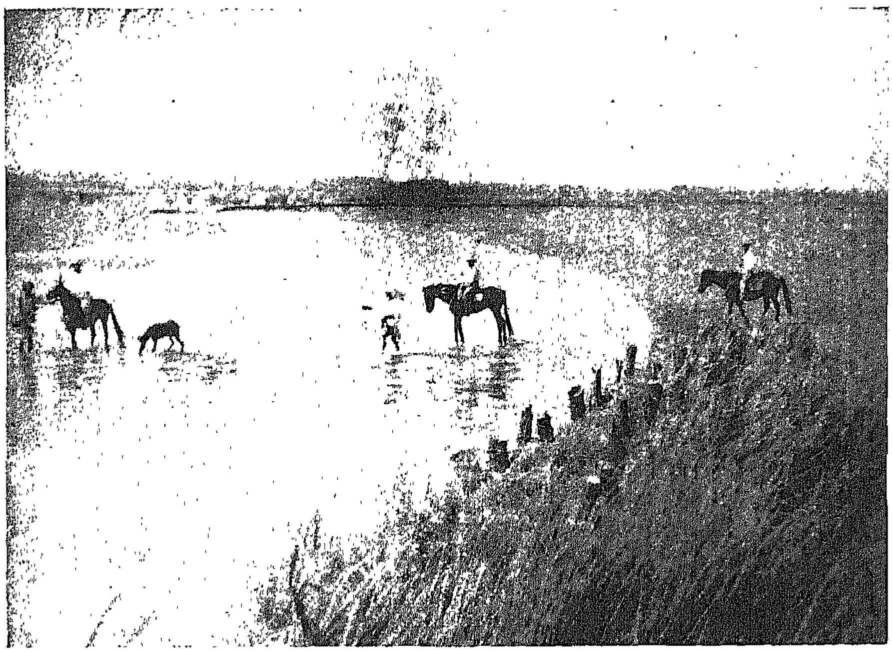


PLATE 21. (i)

Reclamation of the Sil river bed in Attock district starts with brushwood spurs (as in foreground) and the planting of Kana grass to raise the level of the sandy bed (behind)—Para 10.12.

PLATE 21 (ii)

The same spur after surviving its first monsoon, showing that it has been effective in deflecting the main force of the torrent away from the bank. It also shows progress of afforestation on the farther shore now filling up with Kahi, Kana & Sissoo.

10. 18. *Wire crates.*—The usual size for a boulder crate is $10' \times 5' \times 4'$ but half this size is justified where there is danger of unequal subsidence or of overturning by the torrent or where they have to be dropped into deep water. Flat mattresses should be not less than $6' \times 3' \times 1'$ unit size and securely wired together in series. Wire should be of 6 or 8 S. W. G. galvanised woven into a 6″ hexagonal mesh. The weaving of this can be done by driving a row of spikes at 6″ intervals into a beam longer than the required width. The wire is cut to 3 times the length of the netting required and the middle bent round a spike. Weaving is started from one corner and a double twist given round each inter-section. The method is described in detail in *M. E. S. Handbook Vol. III Roads.* The bottom and 2 ends are woven in one piece and the sides separate and the whole tightened up with a crow bar. 65 lbs. of wire are needed for 100 sq. ft. of 6″ mesh. Old bhoosa bale hoop iron can be used also. The various trade proprietary makes of woven wire in wide rolls are all much dearer than crates woven on the spot but the extra cost may be justified if local labour had no experience of wire weaving. Usually the local P.W.D. road repair gang is trained in this work. (See plate No. 10).

10. 19. *Pitched Islands.*—Building a single island, or a series of islands placed in echelon, may serve to draw away from a vulnerable bank the force of the current which is threatening it, or may be used to modify curves of a meander. The island is built in the same way as a spur but is triangular or oval in plan with the upstream point well armoured with stone paving and wire crates. (H. L. Uppal in *C. B. I. Journal,* Jan. 1945).

Chapter XI.

RIVER BANK CONSOLIDATION.

11. 1. All of the Punjab rivers are busy destroying their own banks throughout many hundreds of miles of their courses through the plains. In spite of its name, there are in the Punjab not 5 main rivers but 7 namely Jumna, Sutlej, Beas, Ravi, Chenab, Jhelum, and Indus, though the Ghaggar in flood is quite as destructive, making eight in all. The combined length of their courses in the Punjab plains is about 1840 miles and allowing an average width of 2 miles, which is a very moderate estimate of the land already destroyed, this represents an area of 3680 square mile or 3½% of the province. The detailed figures of length of bank needing protection are in miles:—Jumna 140 (one bank only), Sutlej 380; Beas 90; Ravi 270; Chenab 180; Jhelum 180; Chenab plus Jhelum 50; Trimab and Panjnad 150; Indus 350 (excluding Attock-Mari Indus section); Ghaggar 100 (excluding Patiala). See Plate 1.

11. 2. The land along the top of the river bank is invariably fertile so the cultivator ploughs right to the edge or allows his cattle to graze in it, thus weakening the natural bank which is generally a vertical earth wall liable to slump off in huge chunks with the erosive action of each high flood. This process of attrition is continuous, for the rivers themselves continue to reach unprecedentedly high flood levels owing to the progressive deterioration of conditions in their Himalayan catchments which discharge so much raw sand that their plains channels are constantly being raised in level. So they are capable of broadening their beds at the expense of good land almost indefinitely. Plate 22 ii.

11. 3. What is the cure for this alarming state of affairs? The answer is in proper conservation of the banks themselves. There is a recognised and tried technique for consolidating the natural banks, of rivers, tried at least in a number of more progressive countries such as the U.S.A., and Australia, though not yet in the Punjab. The process is,

(a) lay a line of stone filled wire bolsters along the foot of the existing bank below flood level.

(b) Where the bank is vertical push it down to a slope of approximately the angle of repose of the soil.

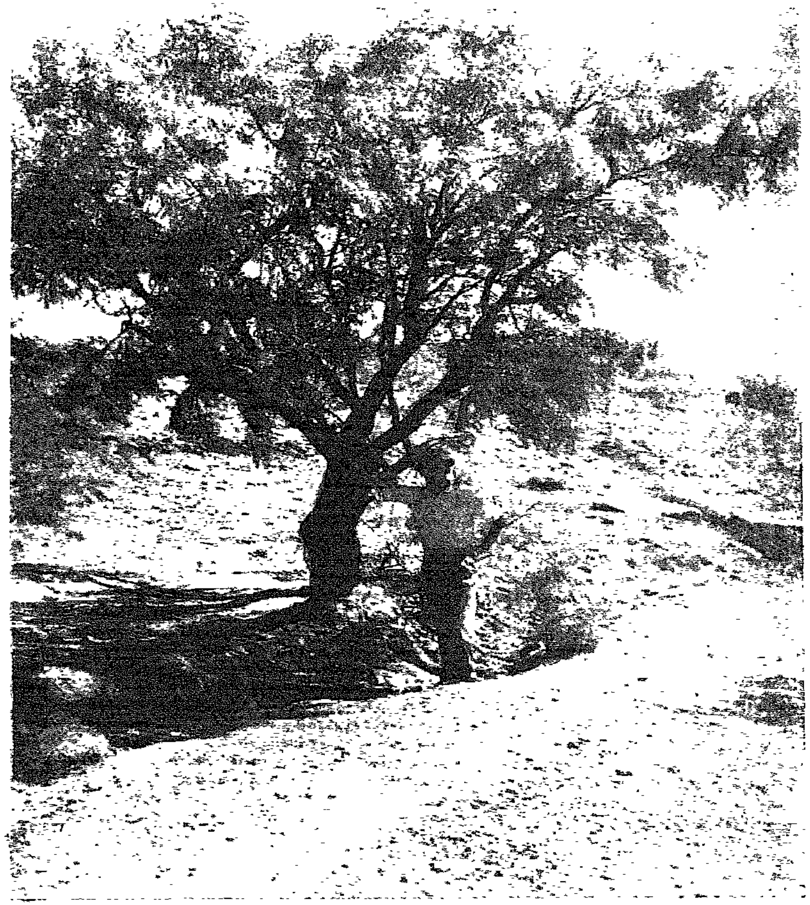


PLATE 22 (i).

A 12-year old mesquite (Prosopis glandulosa) tree form at Fort Munro the 6000 foot hill station of Dera Ghazi Khan district. Only about 10 % of the surviving plants are trees, the rest being a bush type which never grows to more than a bunch of thin sticks.—Para 12.26.

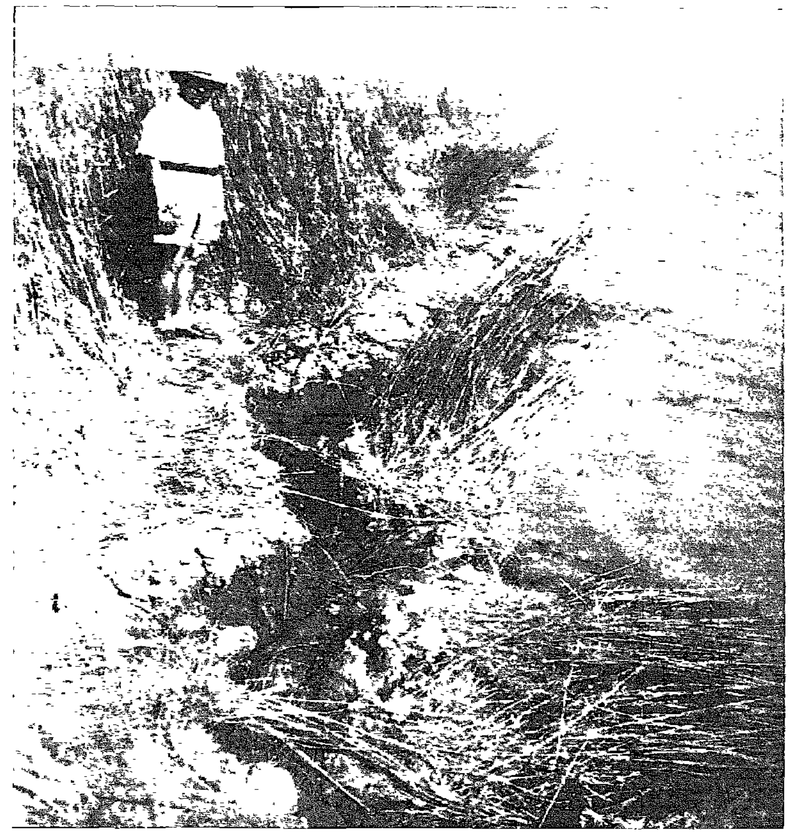


PLATE 22 (ii)

Indus bank near Dera Ghazi Khan showing how heavy grazing has weakened this natural cane-grass cover, so that each clump already isolated by treading, breaks off as the rising flood moistens its roots.

(c) Revet this sloping face completely with every conceivable kind of vegetation which may help to withstand periodic flooding.

(d) Take over a strip of land of say 300 ft. width at the back of the newly established edge and plant this up also with trees and grass, making sure of the rigid and permanent exclusion of cultivation and all grazing animals. This can be done by applying the Land Preservation Act Punjab 1944 (Chos Act), see Appendix II.

(e) Having established a solid sloping bank we now go back to the river bed to reclaim whatever we can of the sandy river bed by means of a gradual canalisation of the river. This is done by erecting groynes or spurs of deeply driven posts wired together across bolsters of stones or packed brushwood, set at an angle of 20° to 25° pointing downstream and jutting out into the stream to form a herring-bone pattern. The effect of these is to form a stilling pool in the shelter of each, where the flood water deposits its load of silt. Figure 41.

(f) As soon as the floods start to subside, these raised beds of silt are planted up with *nara*, *bana*, *kana* and *sissoo* cuttings so that all gains of raw silt are consolidated by means of vegetation.

(g) Low-lying blocks of land subject to inundation during high floods and therefore suited for afforestation rather than cultivation should be provided with a grid of strong earth bunds with stone-faced inlets and outlets. These will serve as a means of reducing flood peaks by the harmless and useful trapping and disposal of a part at least of high floods. Such a bund scheme already exists on the right bank of the Jhelum at Rasul.

11. 4. The extent to which fresh land can thus be reclaimed from the bed of the river itself depends upon a number of factors such as the ratio of winter flow to summer flood, the extent to which the river sand dries up during the hot weather or remains waterlogged during and after the monsoon, the amount of attrition caused by sandstorms picking up the exposed river sand, the width of land already destroyed by river action in ratio to the current flood peaks—i.e., whether the present bed is fully utilised by floods or not,—and the ratio of fine silt in the sand of

the river bed which governs the choice of tree and grass species which can be used in plantation work.

11. 5. In view of the erection of the Bhakra Dam on the Sutlej being the first of the High Dam schemes to be proceeded with, the Sutlej is the obvious first choice for operations, because the effect of the dam will be to eliminate high floods entirely and to leave practically the entire area of old flood-plane available for reclamation. Next would come the Indus itself, for both above and below the Attock gorge there are enormous stretches of flood plain available. Similar areas on the Chenab and Ravi have been partly incorporated in the Grow More Food activities for bringing fresh land under cultivation, but any drop in the price of food grains is likely to throw such land out of cultivation again, leaving it as a bare fallow and therefore much more vulnerable than when covered with grass and trees. The lower reaches of the combined rivers known as Trimab and Panjnad also contain many very wide stretches of waste flood-plane; and the Beas downstream from the main Delhi-Lahore road and railway crossings is another obvious area to tackle.

11. 6. *River Bank Survey Required.*—The first requisite is a rough survey of the river banks by a commission consisting of, say, a forest officer, an irrigation engineer and a revenue officer, who would work down each river in turn to form an estimate of the amount of land available, and to make decisions as to how much of the existing fields must be taken out of cultivation in order to secure a safe margin of shelter-belt. They would also have to decide upon the relative priority of the various tasks, for it will take some years to build up a staff capable of undertaking all this work in addition to the work already in hand along some of the smaller torrents. Sections 5 and 5A of the Land Preservation Act will have to be applied to the areas selected so as to obtain complete control of both grazing and cultivation.

11. 7. Where the flood-plane is a wide one and there is scope for choice of alternative alignments, the whole bed might require to be mapped afresh with a detailed survey of levels, as the meandering of rivers has now been reduced to a fairly accurate study and it can be foretold with some exactness where the channel can best be stabilised. (See para. 11.11). This again would reduce the width of the area to be brought under the Chos Act.

11. 8. *Schemes.*—The Missouri Basin project on which work has actually started provides for 105 major dams, 22 of them of a size comparable with our Bhakra or Kosi projects, so it is hardly surprising that the total estimate amounts to 2000 million dollars. What is of importance to us at the moment is

the courage with which such projects are being tackled in other countries with similar problems. The Missouri engineers have already gone a long way ahead with their afforestation of main river banks. They are concentrating upon river-bank protection by means of afforestation in exactly the way now proposed for the Punjab, namely by an "elastic-sided boot" of shelterbelt to support their pile groynes at all points or reaches threatened by flood action, even before their dams have been built. (Fig. 41). Sir C. C. Inglis' scheme for the Damodar river control in Bengal includes prescriptions for afforestation, and the trapping of sand in retention reservoirs as part of the deflection of the Damodar into the lower bed of another river, the Darkeswar. (*C. B. Irrigation Proceedings,* 1944).

11. 9. Fortunately for the Punjab none of its major rivers behave quite so wildly as does the Kosi, which on its course from Nepal through the plains of Bihar, has shifted its course repeatedly within a pendulum swing of over 70 miles between Purnea and Darbhanga, laying waste some 3000 square miles by dumping sand, blocking communications, spreading malaria and destroying crops. Proposals to confine it with parallel bunds have fortunately been dropped in favour of a more permanent improvement by building a high dam within the hills of Nepal at Baraha Kshetra, but its load of silt which is calculated to be 55 million tons or 32000 acre-feet a year will be a serious menace to the success of the project unless the Nepal government can be persuaded to take in hand a large soil conservation programme. Rai Bahadur A. N. Khosla's estimate is that this river has a minimum winter discharge of 10000 cusecs, a normal flood discharge of 250,000 cusecs, a maximum flood discharge of from 700,000 to 1,000,000 cusecs, and a mean annual discharge of 40 million acre-feet, thus placing it ahead of all the Punjab rivers except the Indus.

11. 10. The meandering of the major Punjab rivers occurs only within the geographical confines of their existing flood-plane. Unlike the Kosi or the other dangerous rivers of Bengal, Assam, Bhutan, and Nepal, which swing through a very large and uncontrollable arc directly they emerge from the confines of the hills, our Punjab rivers are more or less stable *within their existing flood planes,* and it is the outer strip of this flood plane which is proposed for afforestation, in anticipation of the greatly reduced flood peaks, which will obviously be reduced by the building of the Bhakra and other dams upstream. This is merely a logical extension of the conservation of our irregular string of river *belas* which are scattered within the flood planes of our

main rivers, by linking them up in a more or less continuous shelter-belt.

11. 11. Meandering is defined as the adoption of a continually varying sinuous path by the deep water channel (*thalweg*) of an alluvial river, not imposed by external constraint. Conflicting evidence allows relatively few points to emerge in a fairly certain manner, but the factors affecting tortuosity are:—

(a) that erosion leads to tortuosity,

(b) that the soil composing the banks has a definite influence,

(c) that sudden rises in discharge affect tortuosity,

(d) that obstructions such as weirs or bridges increase tortuosity.

Auxiliary points of importance that the mass of evidence shows are

(e) that sharp loops in a river are not a sign of decay,

(f) artificial cut-offs are not successful and cause compensatory lengthening of the channel down-stream and even up-stream.

(g) embankments do not affect tortuosity.

(Central Board of Irrigation Conference Proceedings, 1938).

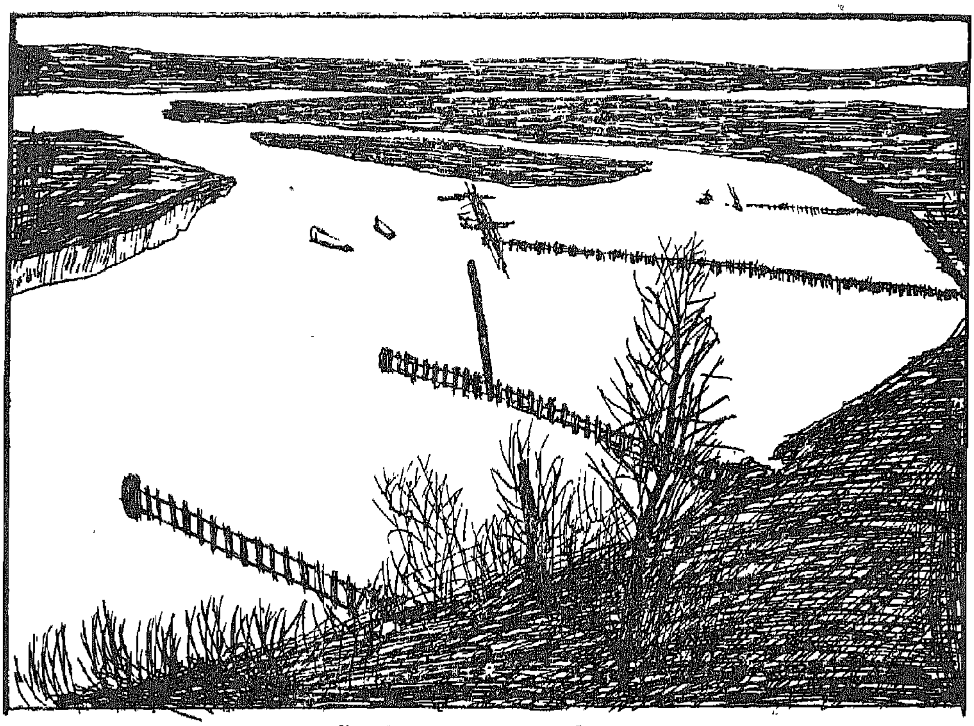
11. 12. For guidance in foretelling the probable movements of our Punjab torrents there are a number of useful papers written, but unfortunately most of them are in foreign technical journals, copies of which are difficult to get, e.g., J. Leighly's Meandering Arroyos of the Dry South West (*Geog. Rev.,* April 1936) has many useful diagrams. The type of curve cut by a river is rhythmic if it is not interfered with, but if the channel "inherited" by the river is blocked by natural obstructions, the curves are irregular. The type of curve is also influenced by whether bank cutting has been accelerated by heavy discharges of silt-laden tributaries from upstream, or whether gullies are eating inwards from the dead base level of the main stream into the adjoining slopes (as is seen in the Betwa and Jumna rivers in the U. P.). If "inherited" meanders or loops are subjected to a greatly increased discharge by the river, they cannot survive and the channel adjusts itself by cutting through the loops and establishing a much straighter course. No bend resembles the arc of a true circle but is rather a parabola. Meanders even under stable conditions generally tend to migrate down-stream though this is a very slow process. Changes also occur between high and low stages of the river because the heavily charged

floods are apt to cut a different pattern of curves from what the normal stream fashions. This is carried to an extreme in our sand torrents which cut a series of minor meanders in the main bed of the torrent which itself has a tortuous course. (J. F. Lutz, *Soil Sci. Soc. Amer.*, 1939).

11. 13. *Alternative Methods of River Control.*—When dealing with river training, irrigation and bridge engineers approach the problem from a rather different point of view, as they naturally have to work to fixed points at which the river must be held, and therefore their proposals for river training have to be much more *pukka.* These consist usually of longitudinal limiting embankments, in an effort to tie the river down to a fixed bed. If this bed is narrow, the river soon fills up the confined bed with an extra deposit of silt, after which it is in a better position to breach the levees and flood the surrounding country, which by that time is at a lower level than the bed itself. The provision of flood control dams within the hills, is also liable to be vitiated by accumulations of silt behind the dams unless these are made with sufficient extra capacity to hold, say, fifty years' accumulation of silt in the pond and still leave enough room for water storage. The proposal of high dams appears to be the better of the two alternatives, and given effective work upstream to reduce the load of silt by preventing it from getting into the stream in the first instance, high dams within the hills become the obvious solution for flood control.

11. 14. Given effective control of floods by this method, the question then arises, how can we utilise the enormous stretches of sandy waste along the banks in the plains, which previously were menaced each year with flood damage, but will now, as a result of the dams being built, no longer be so seriously threatened? The answer is again in afforestation of a broad strip along both banks throughout the entire course in the plains. Once the dam is working we can see just how much of the flood plain is still needed for the greatly reduced peak floods, and all the rest of these sandy deserts of blowing sand can be brought under control and made to produce considerable revenue. If on the other hand the engineers have built enormously expensive longitudinal limiting embankments some distance back from this new reduced flood level, the whole of that money will have been wasted when the dam begins to function upstream.

11. 15. *Maintenance of the Protective Belt.*—Once tree growth has been established on the bank of a stream it must on no account be felled. Many efforts to reclaim stream banks have failed in the end because care was not taken to protect the vegetation on the bank. The thicker the vegetation on the stream



BEFORE

AFTER

FIGURE 41
River Bend Before and After Training.

bank, the better chance it has of surviving heavy floods, even those which overtop the bank and flood the land behind it.

Every opportunity must be taken to establish woodland on the ground behind the stream bank. Our Punjab torrents bring down such terrific and sudden floods that we cannot hope to contain the highest flood peak within the bounds of a partially canalised bed, so that overflow must be expected and provided for. This can best be done by establishing belts of forest of whatever width can be exempted from further field cultivation, with a minimum of 200 feet but preferably 600 feet for dangerous torrents. This is our "elastic-sided boot".

11. 16. It is not likely that individual cultivators will agree to surrendering their river-side fields for the purpose, so that co-operative or panchayat management is essential to secure continuity of management and freedom from the threat of private fellings. The society should take over such land from the owners and if it is *malkiat* the society with government's help should pay rent or recompense the owners suitably for the loss of fields removed from cultivation. The revenue from forest products on such land is likely to be considerable, for *sissoo* and *kikar* generally do well on land subject to occasional flooding. Careful selection fellings can be arranged in the flood belt, although they are not to be allowed on the actual stream bank.

11. 17. *Example of detailed project for the Indus bank in Dera Ghazi Khan.*—In the bela land along the Indus river roughly 3 lacs of acres of land along a river frontage of 270 miles covered with stumps of *kahi* grass are used only for grazing and are otherwise unproductive except for sporadic clearance for cultivation. These clearances do not appear to be regulated or controlled in any way apart from a government grant of Rs. 10 per acre given for encouraging clearance for food production. Very much larger areas could be brought under grain crops by using farm tractors, but before advocating this it is essential to provide some better defence against bank erosion by the Indus itself. This could be done by excluding grazing from, say, a furlong wide strip along the river and any major side channels by applying section 5 of the Land Preservation (Chos) Act and planting it up with all available forms of riverine tree, bush and grass. By dedicating 30,000 acres (say one tenth of the *bela* land) to shelter-belts, the safety and prosperity of the whole tract could be ensured. The very heavy wastage of land from bank erosion in these low-lying *belas* is due to the fact that each clump of *kahi* grass becomes completely isolated and unsupported because of the cattle tracks which beat down the soft earth around each clump. As the river level rises these isolated clumps

collapse into the stream and dissolve, and the rate of loss each year is very heavy. (Plate 22 ii). This may not be entirely preventable but could at least be reduced very greatly by forming an impenetrable belt of plant growth. The species best suited to supplement the existing *kahi* grass are (i) *nara* reed (*Arundo donax*), (ii) *bana* or *sambalu* (*Vitex negundo*), (iii) willow, (iv) poplar, (v) *sissoo*, and (vi) *sarkanda* or *munj* grass. An excellent example can be seen on the Bulewala flood water control bund south-east of Jampur where the Irrigation Branch have produced an impenetrable water barrier by planting *nara* reed along some 3 miles of bund, starting in 1941.

Chapter XII.

WIND EROSION AND DRY FARMING TECHNIQUE.

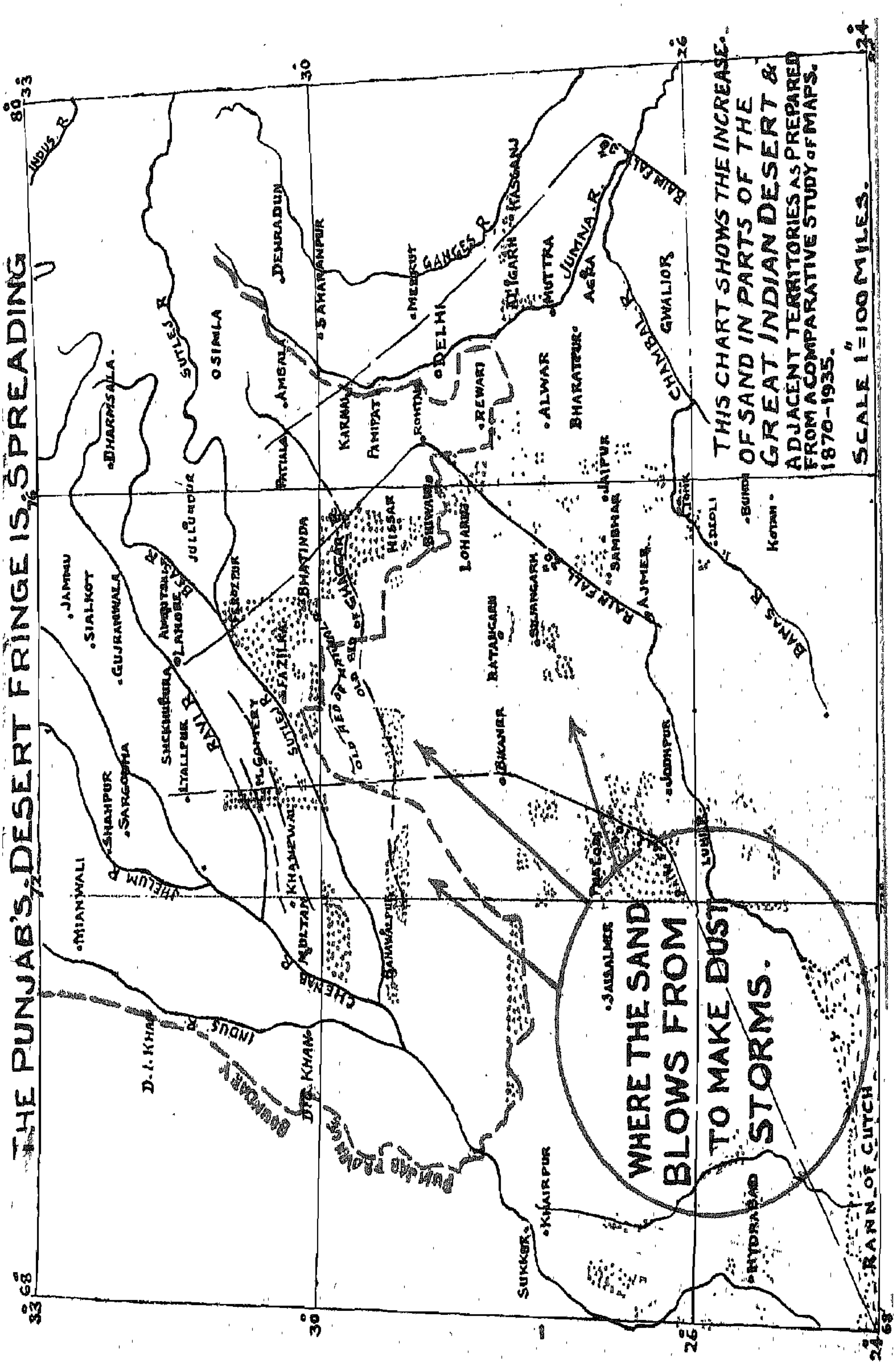
12. 1. Very large blocks of the Punjab plains have been brought under irrigation from one or other of the five rivers, so that there is a green belt of permanent and thoroughly levelled cultivation stretching from Delhi to the Indus. But the southern fringe of this belt is a very ragged one, and the pattern of land use in the southern districts is of the long fingers of commandable land on either side of canal distributaries running far out into unirrigated sandy and often hummocky ground. The natural vegetation of the tract is an open and scattered growth of *van* (*Salvadora oleoides*), *karil* (*Capparis aphylla*) and *jand* (*Prosopis spicigera*) with *phog* (*Calligonum polygonoides*) holding the tops of permanent sand dunes, but this has of course been cleared away entirely wherever irrigation is possible, and in the unirrigated land beyond this scrub is disappearing in face of the constant attrition of grazing, browsing, hacking for fuel supply, and clearance for the erratic cultivation of gram in years of good rainfall.

12. 2. There is a common impression that the various deserts of the world, including the Sahara, the Australian and the Rajputana deserts are all advancing outwards and engulfing fertile land. There are only a few genuine instances of farmsteads becoming absorbed in an advancing tide of windblown sand, and taken as a whole, this impression is a wrong one. Fertile land is not often engulfed, but it very often deteriorates in the ways we have discussed until it is indistinguishable from the adjoining desert. When we speak of the advancing desert therefore we must not picture an engulfing sand-dune swallowing up fertile land; the actual process is a less spectacular but more insidious process of gradual decay from an ecologically stable forest destroyed to make way for cultivation, whose fertility dwindles until the land is merged into the adjoining desert.

Each country has its key position which forms a physical barrier against the further spread of arid conditions. In the Punjab the Salt Range forms a buffer between the fertile Eastern Punjab and the arid Indus plains; the low hills of the Salt Range are the home of a virile Mohammadan peasantry who form the backbone of the Indian Army, but they will have to

beat their swords into planting mattocks if their country is to remain a land worth fighting for. Unfortunately, the peasants as a whole are not tree lovers; their desert heredity has perhaps rendered them out of sympathy with trees. and the pressure of their ever-expanding human and animal population has justified a ruthless war on trees, so that forest conservation is not only unpopular but is automatically doomed to failure unless a complete change of heart can be brought about by means of a well-directed and practical educational campaign. In the moister half of the Punjab to the east a more biddable peasantry have less inclination to destroy trees and less excuse for doing so, so that conservation does stand a better chance of success.

12. 3. At the Silvicultural Conference of 1945, Lt. Col. Westland Wright produced a map of the Punjab and Sind on which was entered the records of sand movement as indicated by the surveys done by the Survey of India in 1870 and again for the identical ground in 1935. This record is not complete, as both surveys are not available for the whole area, but enough data is available to show very clearly that in the 65 year interval, and in spite of large irrigation developments, shifting sand has increased to an alarming extent. (Fig. 42). The indication is that desert conditions and shifting sand are advancing north-east-wards out of Sind and Rajputana into the Punjab and towards Lahore and Delhi at a rate of half-a-mile a year. This is borne out by actual experience of many individual villages in the districts of Hissar, Gurgaon, Ferozpur; Faridkot, Bahawalpur and Bikaner States; and again further west in Multan, Muzaffargarh, Jhang and Shahpur; the *Thal* of Mianwali; and beyond the Indus in Dera Ghazi Khan and Dera Ismail Khan. Most of these places are climatically in the belt of low rainfall where the average of, say, 12 inches seldom occurs but the actuals from year to year may be nothing at all in one year and 20 inches in the next. In the districts with a better rainfall but with big stretches of unirrigated plains such as are found in Jullundur, Ambala, Karnal and Rohtak in the east and in Rawalpindi. Jhelum and Attock in the west, the movement of sand is more strictly localised but is none the less a serious handicap for agriculture. The sand here is usually derived from the nearest open torrent bed along which the sand eroded from neighbouring uplands has been dumped. Another source is of course the main river channels which are often miles wide. From both these sources the sand is whipped up by the hot summer winds and carried considerable distances away from the actual stream-bed. for instance sand from the Markanda torrent in the plains of Ambala district has practically buried villages two miles away


THE PUNJAB'S DESERT FRINGE IS SPREADING
WHERE THE SAND BLOWS FROM TO MAKE DUST STORMS.
THIS CHART SHOWS THE INCREASE OF SAND IN PARTS OF THE GREAT INDIAN DESERT & ADJACENT TERRITORIES AS PREPARED FROM A COMPARATIVE STUDY OF MAPS. 1870-1935.
SCALE 1" = 100 MILES.
MIANWALI
D. I. KHAN
INDUS R.
BOUNDARY
PUNJAB FRONTIER
D. G. KHAN
JHELUM R.
SHAHPUR
SARGODHA
JAMMU
SIALKOT
GUJRANWALA
SHEKHUPURA
LYALLPUR
RAVI R.
LAHORE
AMRITSAR
BEAS R.
JULLUNDUR
DHARMSALA
SUTLEJ R.
SIMLA
CHENAB R.
MULTAN
KHANEWAL
M. GOMERY
SUTLEJ R.
FAZILKA
FEROZPUR
BHATINDA
OLD BED OF HAKRA
OLD BED OF GHAGGAR R.
PATIALA
AMBALA
DEHRADUN
SAHARANPUR
KARNAL
PANIPAT
BAHAWALPUR
HISSAR
ROHTAK
MEERUT
DELHI
BHIWANI
LOHARU
REWARI
GANGES R.
BIKANER
RATANGARH
SUJANGARH
ALIGARH
KASGANJ
ALWAR
MUTTRA
BHARATPUR
AGRA
JUMNA R.
SUKKUR
KHAIRPUR
JAISALMER
PHALODI
JAIPUR
SAMBHAR
RAINFALL 20
RAINFALL 30
AJMER
JODHPUR
CHAMBAL R.
GWALIOR
TONK
LUNI R.
DEOLI
BUNDI
KOTAH
HYDRABAD
BANAS R.
RANN OF CUTCH

from its eastern bank. Dr. D. V. Shuhart in his report on Soil and Water Conservation in India 1946 has issued a strong warning on such local dangers in the eastern Punjab plains.

12. 4. The phrase "desert fringe" has been somewhat loosely applied to the southern belt from Gurgaon to Multan, but it will be seen from the above that the problem of sand fixation is by no means confined to this belt. The phenomenon of a local "desert fringe" round the perimeter of any considerable town in areas of low rainfall is a commonly recognised feature in north and west Africa, and Dr. A. L. Griffith has recently produced air-photos of towns in Sind and Rajputana showing a very obvious "desert fringe" caused by heavy grazing and browsing of town herds. (*Ind. For.* May 1946). This is likely to become an increasingly common feature in towns such as Bhiwani, Hissar, Bhatinda, Abohar, Arafwala, and Mailsi, to mention only a few whose perimeter is partly unirrigated and subject to strong wind erosion.

12. 5. *Dynamics of Wind Erosion.*—The study of the mechanics of wind action as affecting soils has lagged far behind the parallel problem of water action and it is only recently that laboratory research workers have been able to produce any useful data to help us to understand this problem. Canadian workers in the Dominion Experimental Station at Swift Current, Saskatchewan, Canada, have shown that much valuable information can be obtained from: (1) a wind tunnel built as a permanent laboratory fixture, with electric fans blowing through a honeycomb of small appertures, the soil samples being kept under observation in a glass-sided tunnel somewhat similar to those used by the Indian Irrigation Research Institute in their studies of water action, (2) a portable apparatus for use in the field, using an automobile engine to drive the fan in a shorter length of tunnel, thus giving a larger choice of soil samples and linking up laboratory results with what is actually found in the field.

12. 6. *Comparison of Wind and Water Erosion.*—The mechanical processes governing the movement of soil by water and wind are surprisingly similar in much the same way as the turbulences of a liquid and a gas are similar. The performance of the individual grain disturbed on the ground surface and forced to move downstream or down-wind is similar; in both cases there are three phases, namely (1) entrainment, (2) transportation, and (3) deposition. In both cases no movement whatever can take place until the smallest grain submits to the forces which are attempting to move it, but once movement has started

it tends to become cumulative, for the bumping and jostling effect of moving grains along a river bed is very similar to what happens within a few inches above ground level when a wind storm sets the surface of a field in motion. Those particles nearest the ground slip over one another but those which acquire faster motion become projectiles and disturb others.

12. 7. In wind erosion however there appears to be more waywardness owing to the interplay of forces and factors difficult to measure or anticipate. F. J. Malina has analysed these factors thus:—

Features of Wind itself.	Characters of surface.	Topography	Characters of soil.	Surface effects.
Speed	Roughness	Flat	Texture	Removal.
Direction	Plant cover	Undulating	Structure	Deposition.
Structure	Obstructions	Broken	Organic content	Surface markings.
Temperature	Temperature		Moisture content	Dune formation.
Humidity			Soil binders.	
Burden carried				

(F. J. Malina in *Trans. Amer. Geophys. Union,* 1943; Recent Developments in Dynamics of Wind Erosion).

It is the interplay of any or all of these variables which makes any accurate estimate of soil movement impossible, and so our counter-measures can only be evolved through a process of trial and error before we can decide upon the cheapest effective anchorage.

12. 8. In considering the effect of wind it must be borne in mind that the turbulence of an air current is very similar to the turbulence of mud mixing in a stream of clear water, as it tends to form a sort of cushion of arrested movement around any obstacle in its path. It is because of this that even a single row of widely spaced trees has an appreciable stilling effect. It must also be remembered that once fine grains of soil have become air-borne it is quite difficult to get them down to ground again, so that all our efforts must be to prevent them from becoming air-borne. This can best be done by multiplying the number of wind-breaks.

12. 9. W. S. Chepil and R. A. Milne ("Wind Erosion of Soil in Relation to Roughness of Surface", *Soil Science,* December 1941) found that soil particles up to 0.8 mm. diameter making up a field with a smooth dry pulverised fallow, began to move when the wind reached a velocity of 13 to 15 miles per hour at 1 ft. above ground. For ordinary wind velocities, 93%

of the total wind-borne soil is carried at less than 1 ft. height and only a small trace of soil is wind borne above 38 inches above ground level. The very finest particles do however rise to very great heights and remain suspended for long periods of time. Phenomenally high winds do of course whip up very large quantities of soil. Measurements made of a dust storm of February 1937 showed that this storm in Texas whipped up as a suspended load 200 lbs. per acre which was transported 500 miles and dumped in Iowa on snow. Analysis of samples showed that this wind-borne material contained 3 times as much humus as the best remaining soil of the Texas region whence it was picked up.

12. 10. Similar measurements for northern India show that apart from such spectacular single storms there is a steady seasonal movement of dust averaging: 4 days in March, 9 in April, 19 in May, 12 in June and 5 in July; and that 1 inch of dust is deposited every 7 years, richer in plant nutrients than the *arid zones whence it is derived.* (Abhiswar Sen in *Current Science,* October 1945).

12. 11. The rate at which soil can be moved by wind varies inversely with the roughness of the surface and thus explains why any form of ridging placed at right angles to the direction of the prevailing wind tends to reduce soil loss. Even ordinary plough furrows, if aligned at right angles to the prevailing wind, will have an appreciable effect in stopping movement, as is shown by the following data, collected by W. S. Chepil and J. L. Doughty in the wind-tunnel experiments which they carried on at the Soil Research Laboratory, Dominion Experimental Station, Swift Current, Saskatchewan.

Soil Treatment.	Amount of soil in grains moved in 5 minutes by a 22 m.p.h. wind at 2 inches height.		
	Sandy loam.	Loam.	Clay loam.
a. Level, bare surface	110	215	209
b. ridges 1½ inch high, 7 inches wide ...	75	59	87
c. level surface as in (a) but with ¼ ton per acre straw	6	34	17
d. Ridges as in (b) plus straw ...	30	13	12

These wind tunnel experiments can simulate natural conditions with wind speeds upto 35 m.p.h. provided by a fan worked from an ordinary car engine. The moving air is passed through a metal honeycomb to ensure equal distribution within the tunnel.

12. 12. *Fixation of Shifting Sand.*—This is an old problem which has been tackled in many different countries, but more commonly as a sea-shore dune reclamation than as a battle against inland desert movements. Historical examples can be studied in the Landes on the west coast of France and in the Culbin Sands of the Morayshire coast of Scotland. In both of these the engineers tackled the problem with simple engineering works but eventually found that vegetation was in the end the surest defence.

The standard technique in both these instances has been to raise an artificial dune by planting a line of wooden palisade with a space between each post. This palisade can be made out of half-buried old railway sleepers, or rough poles or saplings with their branches still attached; the main point being that spaces must be left for the sand to filter through to the leaward side, and thus build up to a higher level. As the palisade becomes almost buried, the pieces are loosened and raised with a crowbar, so that the dune continues to build up around the fence. When this dune has reached the desired height, sufficient to give some shelter on its leaward side, it is then consolidated with whatever vegetation can be persuaded to grow on sand in that locality.

In the Landes and Culbin, the great stand-by is marram or spartina grass *for the dune itself, and for the flat ground in rear* of the dune, tree growth can usually be established by using some sort of low grass or brushwood hurdle as a combined mulch and sand anchor. Thus the Landes which 150 years ago formed one of the worst malarial zones in Europe, have been transformed into a prosperous and healthy countryside with a resin and timber industry based upon the maritime pine. Similar work is being done in the eastern sea-board of U.S.A. using *Ammophila* spp. and on inland sites *Calamovilfa* grasses, while the pines are supplemented with *Robinia pseudacacia.*

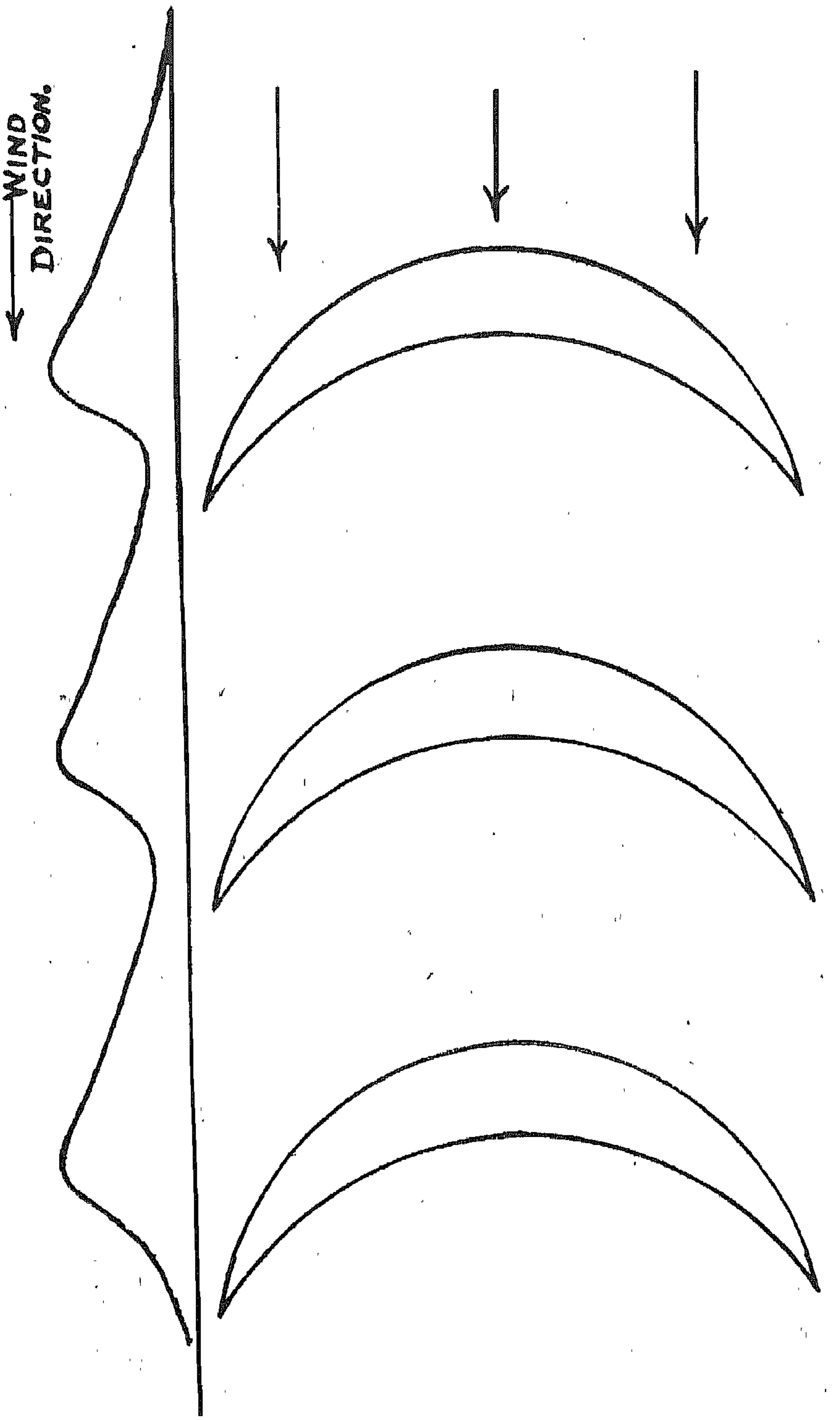
12. 13. The desert sands of the Punjab desert fringe may not yield so easily to treatment, and we require to know much more about the cultivation and silvicultural demands of our desert shrub and tree species than we know now, before we can emulate the success of the French and Scottish pioneers. Our main stand-by must be the *sarkanda* grass (*Saccharum munja*) which can be relied upon to grow in most of our desert soils with some moisture, but in the Thal dunes it is restricted to the firmer ground on the lower levels and will not climb the steep dry faces of the higher dunes. *As alternatives we must therefore* study the local flora and see what else we can get to grow—e.g., the camel thorn (*Alhagi camelorum*) or the leafless *phog* (*Calligonum*

polygonoides), as well as continuing the search for both Indian and imported sand-loving grasses.

12. 14. The mechanics of sand movement must also be studied. Drift sand varies in its origin. It may be derived from marine beaches, from the erosion of barren sandstone hills, or the unconsolidated sandy beds of the Siwalik and similar geological deposits, or it may be from river beds which themselves act as quarries from which sand can be re-distributed across the countryside. In the case of both the larger rivers and of the smaller foothill torrents, the coarser sand is the first to be dumped by the stream, while the finer particles are carried farther out into the plains or down to the sea itself, so that one naturally expects to find the coarsest granular sand nearest the hills which form a river's catchment. Once a bed of sand becomes exposed to wind action, however, it starts moving in the direction in the prevailing wind and in its movement it acts as a sandpaper and recruits more sand from the ground it gets blown over. The "threshold velocity" or the strength of wind required to start particles moving, is lower for sand-dunes than it is for non-eroded fields, hence the ease with which dunes once formed can submerge good fields. (W. S. Chepil: *Soil Science* for Nov. and Dec. 1945).

12. 15. Dr. A. L. Griffith has pointed out that in areas of very strong and constant winds which persist from one direction only, dunes are formed parallel to the wind direction, as is found in southern Sind where very high winds beat in constantly from the sea over the Rann of Cutch (which itself used to be a swamp but is now drying up into sand-dunes). In the voluminous Australian literature on the subject of sand-dunes and wind erosion, the occurrence of dunes *parallel* to the wind direction has not been remarked upon, so it must be presumed that the Sind winds are stronger than any which cause the inland dune formations in Australia. Further inland, and after the wind has moderated somewhat, the typical sand dunes begin as a series of many little wavy longitudinal lines, but gradually grow in height and width by combining into fewer and larger ridges, which now run at right angles to the prevailing wind.

12. 16. The typical sand-dune has a gentle slope of from 5 to 10 degrees to windward and a very much steeper slope of perhaps 30° to leaward, the explanation being that the wind tends to push or jostle the individual particles onwards and upwards until the dune tip reaches a height which tends to become constant for any particular area, depending upon the strength of the prevailing wind, the average size of sand grain, the amount of moisture available as rain, dew, etc., and the presence or absence



SHAPE OF TYPICAL SAND-DUNE, PARA 12·16.

FIGURE 43.

of vegetation. If ridges grow on till the whole area is choked with sand, transverse ridges may succeed the long ones and spoil the symmetrical pattern. Figure 43.

In areas where dunes are common, each one is placed transversely to the direction of the wind, and is crescent shaped, the reason being that the hill acts as a wind break and the sand drops more abruptly into the cup or pocket to leaward, while it is carried a longer distance beyond the unprotected lower wings. The whole dune is liable to move forward by the transference of grains from the windward to the leaward going on continuously, or at least during periods of high wind. Very high dunes move very slowly indeed, and in fact tend to become geographically fixed, perhaps altering a few feet a year, whereas a dune only a foot high may shift several feet in an hour and possibly 50 feet or so during the course of a severe wind storm.

This bodily forward movement is a most dangerous factor from the point of view of blocking roads and railways, and large sums of money are often spent ineffectively by engineers in their efforts to keep them clear by means of chutes, or blowers, the principle of the latter being the same as a silt extractor in a canal, namely to raise the base level of the track and let the heavier sand be carried through below it. Where the danger to communications is serious, the problem should be tackled by the forest department taking up wide strips of land for sand fixation so as to leave the road or rail track free. In one case reported recently from America, the shifting dunes could only be brought under control by laying down a mulch of cut grass and brushwood which had to be brought in by lorry from a considerable distance. To stop this from blowing away it had itself to be pegged down, but it served the purpose of allowing sown grass to come up and take charge.

12. §17. The use of pulse and other annual leguminous crop plants such as gram is a simple means of establishing plant growth on dunes, but most of these being winter annuals do not provide a cover when they are most needed, during the hot summer season. It is therefore generally worth while to take some extra trouble over securing some more permanent plant cover by planting clumps of *sarkanda*. Where ploughing is possible and the soil contains some admixture of clay, as in Hissar, the technique followed on the Government Livestock Farm is to plough fairly deeply to about 6", and then by making a double-turn of the plough to throw up a slight bank every 15 yards or so, which will retain the rainfall and secure good seepage. *Anjan* grass sown in the ploughed land has formed a complete and apparently permanent soil covering which is capable of surviving

long drought periods and can be either cut or grazed. Such a cultivated plant cover is the best insurance against the formation of incipient dunes which are a feature of the surrounding arable land in the Hissar district.

12. 18. *Land Use in the Desert Fringe.*—N. V. Kanitkar's "Dry Farming in India" published as *Scientific Monograph No.* 15 of the Imperial Council of Agricultural Research, is an admirable summary, which should be in the hands of all soil conservation workers. His two chapters on the disposal of rain water are particularly important. He gives the area of the Punjab dependent upon a precarious and erratic rainfall untouched by irrigation as 16 million acres, plus 2 million in the Punjab States, out of a total of 77 million acres of India's dry zone which supports 59 million humans and 45 million cattle. His data for our desert fringe were collected from Rohtak, which was chosen for a dry farming experiment beginning in 1935 out of an allocation of I. C. A. R. funds, and his findings on dry farming practices are therefore applicable to the greater portion of our "desert fringe", so are fully discussed in para. 12. 32 onwards. Vast areas of land with a rainfall of 3 to 15 inches in the Punjab-Sind-Rajputana-Baluchistan block of country are showing increasing signs of aridity, and this aridity is also showing definite signs of spreading and extending into lands previously considered safe from desert influences. Two-thirds of the entire area of Bahawalpur State are described as *cholistan* in which cultivation is only possible if special water-trapping has been done to secure infiltration of all the rain.

During the last 75 years, since first the Punjab was confronted with a fuel famine for railway engines then burning wood, and the foresters established Changa Manga irrigated plantation to meet this shortage, the forest department has built up a body of experience in desert fringe reclamation which is parallel with, but goes further than, orthodox agricultural methods. Tree crops of sorts can be maintained indefinitely on subsoil moisture in many tracts with a high water level of say 10 ft. but they must have some sort of irrigation during the first two or three seasons. From afforestation experiments in the arid low hills of Campbellpur district we know of a number of tree species suitable for use in desert fringe shelter-belts. We also know that where no timber trees will persist owing to drought or physiological water shortage, many shrubs and some cane grasses can be used as shelter-belts and wind-breaks. We also know that where flood water is available it can be made use of over a much greater area than can be dealt with by orthodox field husbandry, by what in America is called "water spreading",

the primitive technique of the Navajo Red Indians of New Mexico and Arizona having been greatly improved under the Roosevelt conservation programme. In the Punjab we have applied the Changa Manga technique to a variety of sites, soils and irrigation conditions, and having in many places failed to grow timber trees we can confidently undertake to produce efficient shelter-belts.

12. 19. Irrespective of whether any of this desert fringe is now producing any *farm crops or worthwhile grazing*, or nothing at all, it can all be improved in terms of:—

(a) establishing a better water regime,

(b) stopping movement of shifting sand,

(c) establishing a more permanent and better livelihood for present occupants,

(d) absorbing fresh settlement of demobilised men,

(e) exerting a modifying influence on climate, run-off and flood conditions both upon the areas treated and upon neighbouring districts in which increasing aridity is already evident.

12. 20. The success of any such reclamation depends entirely upon the water regime. We must therefore start by surveying each administrative or geographical unit (say each tahsil of the Punjab) and breaking it up into one or other of the following groups:—

(i) Land already under regular irrigation either from perennial or inundation canals, or from wells.

(ii) Land regularly subject to flooding along riverine tracts.

(iii) Land not at present receiving flood water but which could be incorporated in a water-spreading project, by using waste from the tails of existing canals or by leading flood water further along prepared channels than it normally goes.

(iv) Land which is not included in any of the above but which has an underground water-table level sufficiently near the surface to justify pumping and redistribution by surface channels or afforestation.

(v) Land which has no accessible water-table and which is entirely dependent upon its own scanty rainfall.

All the above groups except No. (i) can have their water regime improved enormously by means of water catching and spreading. We must capitalise by catching every available drop of moisture whether emanating from rivers, subsoil storage, or

rainfall, and by getting as much as possible of all these redistributed in order to build up the field moisture capacity of every acre of arid land.

12. 21. Having prepared a rough survey and classification of the land on these lines we have next to undertake a colossal amount of earth working, and this falls under the main heads of (a) terracing, (b) water spreading, (c) working the surface soil to make and keep it more absorptive, (d) subsoiling. All of these are dealt with under appropriate heads in earlier chapters.

12. 22. Having established the best possible system of water catching by all these methods it now remains to make the best use of the ground in terms of introducing the most suitable permanent dry farming, afforestation, and shelter-belt practice. Whatever is given out for ordinary cultivation should be on a definite understanding of safeguards:—e.g., no browsing animals whatever; ploughing to be along the contour; mulching as per best local practice; maintenance of terrace bunds and sluices; acceptable rotation of crops to be prescribed; maintenance of whatever shelter-belts have been established on neighbouring terrace bunds. The remainder of the ground must be under shelter-belts or permanent grass-land. In any case grazing must be under very strict control.

For the Muzaffargarh Thal K. S. Allah Bakhsh in his tour note of March 1945 blames the infertility of this desert tract on:—(1) wind erosion removing the finer top soil, (2) overgrazing and browsing, (3) loss of humus by clearing land for fugitive and erratic gram cultivation in years of reasonably good rainfall, (4) shifting sand wherever plant cover has been destroyed. He therefore recommends, (1) closures by rotation, (2) shelter-belts by application of the Colony Act, and, (3) large blocks of forest plantation by means of irrigation or inundation, whichever may be available.

12. 23. *Uses of Saccharum grass.*—Afforestation need not necessarily be with timber trees and much of the desert fringe in its present condition simply will not produce them. We can however do a great deal with the cane grasses (*Saccharum munja* and *Saccharum arundinaceum*) which have previously been treated as weeds in the Punjab, and also with *Saccharum spontaneum* (*kahi*) which has so far only been utilised in the reclamation of torrent beds.)

The use in Uganda of similar coarse grasses grown as a 3 or 4-year fallow is a recent innovation, the importance of which has not yet been appreciated in India either in silviculture or agriculture. Any coarse cane grass will serve the purpose, as they all produce a very large bulk of cane, leaves and

PLATE 23 (i)

The first stage of the defensive strip of shelter-belt is to establish a dense mass of sirkanda cane grass. This alone and without any trees is capable of controlling wind-erosion.—Para 12.23.

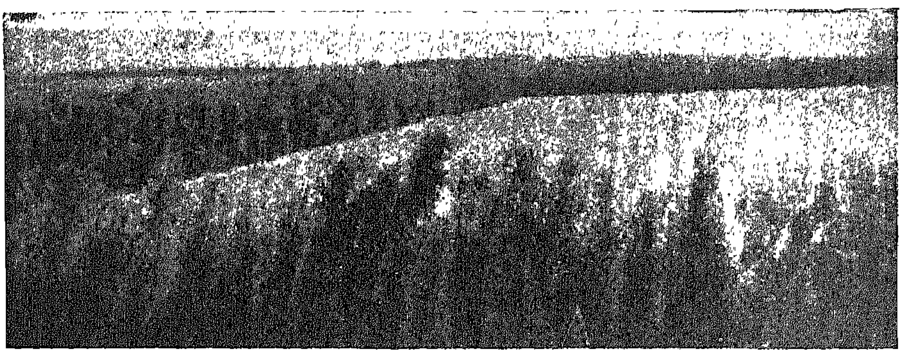


PLATE 23 (ii)

Six year old]shelter-belt protecting field of cotton. Willbarger County, Texas.

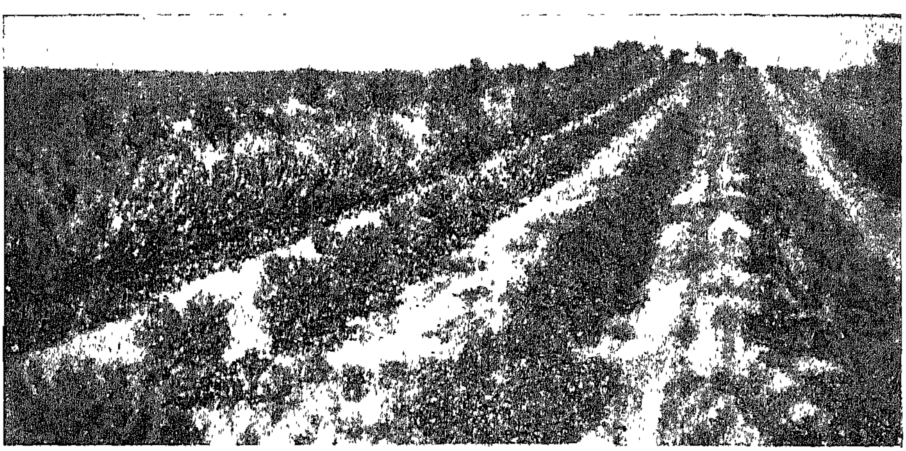


PLATE 23 (iii)

Young orchard of peach and plum protected by a 5-year-old shelter-belt on left containing 3 rows of trees planted close. Paducah, Texas.—Para 12.29.

roots from a minimum of moisture. It serves a twofold purpose, firstly by covering the fallow land wih a mat of vegetation it reduces surface sheetwash to a minimum, and secondly it provides a mass of vegetable matter which when ploughed under, helps to build up a far better tilth, particularly where sheet-wash has already swept away the top-soil and left only a clay or kankar subsoil exposed.)

12. 24. Where *Saccharum munja* is at all prolific, as it may readily become under the improved water regime of our proposals, its roots are so big as to present a real problem to the individual cultivator with only his bullocks and a light plough and even after burning the grass tops. The answer is again in mechanised equipment, but the cultivator can only secure its aid either through collective farming, or if government continues to provide the necessary machines and trained staff over a period of years for the proper maintenance of all these conservation items.

12. 25. The potential value of grass as a means not only of preventing soil erosion but of actively building up a better tilth is summarised clearly in the newly published *Imperial Agriculture Bureaux' Joint Publication No.* 6—"Alternate Husbandry". From this it would appear that under arid conditions a fairly long ley under grass should be followed by a fairly long period under ordinary crops, because the first crop after grass in arid land may be disappointing and the gain is likely to be shown only by subsequent crops which profit by the gradual breaking down in the soil of the grass roots and stems. I suggest that 4 years under cane grass followed by 4 years of other crops should be given widespread trials under all the various combinations of soil and moisture presented by the desert fringe country. We also must learn how far we can eliminate burning which at present is the cultivators' method of exterminating cane grass from any ground he is preparing as a seed bed. The roots are often so massive as to be obstacles even to a heavy mechanised plough, and will in any case take years to rot down unless pulverised before being ploughed under.

It has previously been thought that arid zone soils were slow in breaking down elements of plant food because they were devoid of bacteria, but this has been disproved by Feher and Killian whose paper in *Soil Science Soc. Amer.*, 1939, shows that bacteriologically desert soils are very active and can therefore absorb much humus.

12. 26. *Tree Shelter-belts.*—(Where the contour terrace bunds are at right angles to the prevailing wind these should be heavily stocked as wind-breaks. Where the contour terrace system falls

parallel to the prevailing wind then a separate series of windbreaks of grass, trees and bushes must be established, preferably on a system of low bunds at right angles to the wind. The ideal form of shelterbelt to break the force of the desiccating summer west wind is probably an outer and lower fringe of *Agaves*, then cane grass and shrubs leading up to trees in the rear. The trees themselves should be selected to give a maximum of screening effect, for instance alternate *kikar* and mesquite, with the squat mesquite filling up the gaps between the taller and more open crowned *kikar*.] Similarly *bakain* can be alternated with the bushier *frash*. Other species which should be of use in shelterbelts are:—

Trees—Prosopis juliflora, and spicigera.
Acacia senegal, farnesiana, modesta, catechu, leucophloea, arabica.
Tamarix articulata, dioica.
Populus euphratica.
Zizyphus jujuba.
Leucaena glauca.
Maclura aurantiaca.
Melia azedarach.
Salvadora oleoides.
Capparis aphylla.
Casuarina equisetifolia (subject to local trials).

Shrubs—Agave spp.
Sesbania aegyptiaca, aculeata.
Cassia spp.
Indigofera paucifolia.
Calligonum polygonoides.
Alhagi camelorum.
Opuntia dillenii and nigricans.
Vitex negundo.
Otostegia limbata (*chitti bui* of Attock).

Grasses—Saccharum munja, arundinaceum, spontaneum.
Cynodon dactylon.
Eleusine flagellata.
Andropogon laniger.
Panicum antidotale.
Cenchrus ciliaris.
Eulaliopsis binata (subject to local trials).

12. 27. Silva's experiments with arid zone tree species show that many tree species including most of those now listed, can be grown in areas of very low rainfall provided that effective water-catching is secured by careful contouring either by contour

bunds, in which case sowings do best in the borrow pits, or by deep ploughing and double-furrows at intervals which themselves form small bunds. Dr. A. L. Griffith has summarised the essential points learnt from Silva Punjab's 4 plots as follows:—

(a) complete closure essential.

(b) contour soil working before sowing in lines at about 6" × 6".

(c) sow plenty seed, sow early and sow it in lines, not broadcast.

(d) work soil between lines after each shower but don't disturb plants. Never let soil surface cake.

(e) keep down weeds but do not disturb the local vegetation which appears, except in the lines.

(f) thin out lines as and when necessary.

12. 28. From this it will be realised that desert afforestation has to follow closely upon the rules established for dry farming (see 12. 32). Points in technique which have yet to be worked out are:—

(a) Size and spacing of contour bunds in flat sandy desert.

(b) Best mixture and spacing of species on bunds and also in larger shelter-belt plantations.

(c) Maintenance of both of these against farm animals.

(d) Application of the Hissar technique for other fodder grasses where *anjan* will not persist (see 4. 14 (a)).

(e) Trials with *sirkanda* grass as a manurial crop (12.23 to 25).

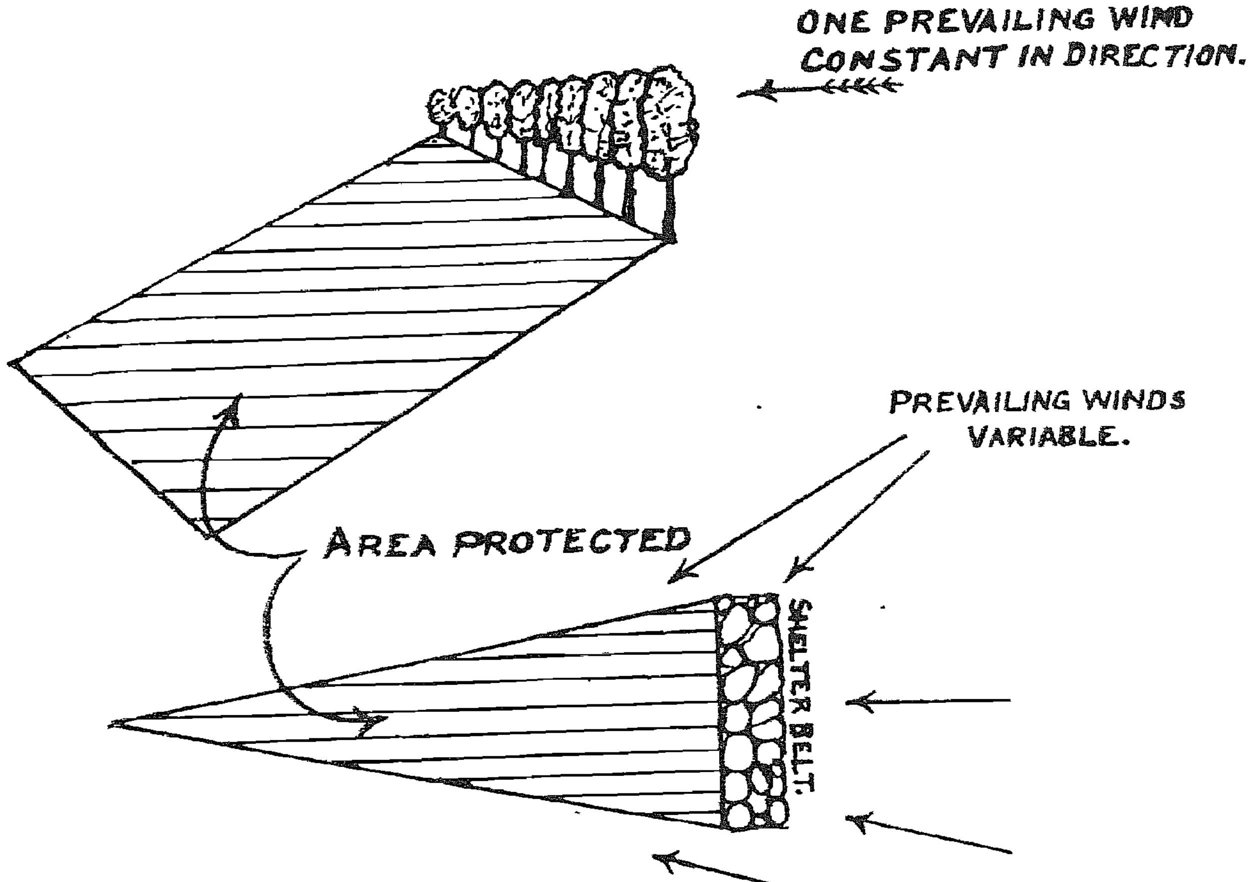
(f) Permissible grazing incidence on improved and unimproved desert grasslands.

(g) Rotational closures for *kahi* grass in partially reclaimed torrent beds.

(h) Consolidation of holdings in sparsely populated sandy land.

(i) Alternative community organisations where co-operative societies for land reclamation have so far not succeeded.

12. 29. *The Function and Layout of Wind-breaks and Shelter-belts.*—Where the damaging wind is constantly from one fixed direction, there can be no doubt as to how the wind-breaks should be aligned. They must be at right angles to the wind force. The larger the number of replications of parallel lines the better, as repeated lines, even if well spaced out, tend to give a



AREA SHELTERED BY A SHELTER-BELT. (TO ILLUSTRATE PARA 12·29.)

FIGURE 43A

cumulative amount of shelter. Where winds are variable and shifting, secondary wind-breaks may be needed at right angles to the alternative wind or else more frequent wind-breaks in the primary direction may serve the purpose. When the wind is constant, one wind-break should give effective shelter to an area of a width equal to 15 to 20 times the height of its trees, and of a rectangular shape. When the wind comes from two directions, the shape of the area sheltered alters to a triangle and the area is greatly reduced. Figures 44 to 46.

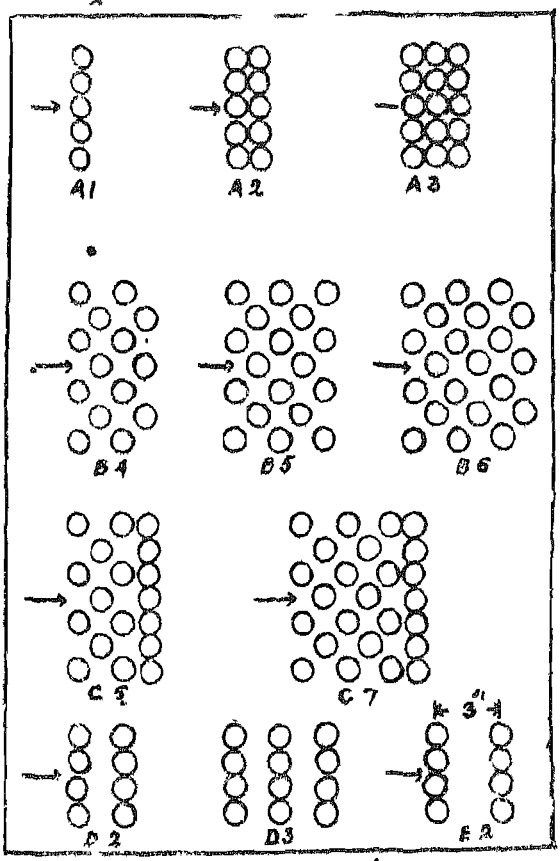
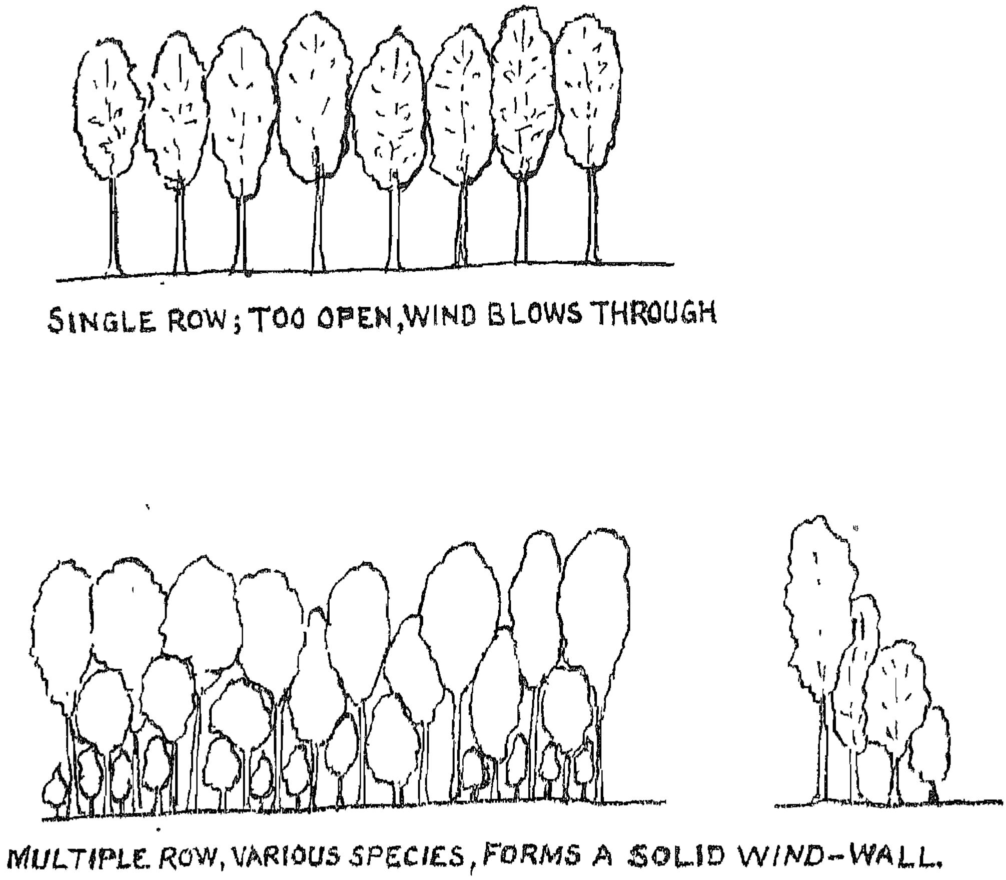


Figure 44

Arrangement of model trees tested in windbreak experiments Soil Conservation Station Saskatchewan

Arrangement	Relative value of Whole Belt	No. of trees per 4H width.	Shielding Effectiveness per tree
A-1	37	4	9.3
A-2	63	8	7.9
D-2	60	8	7 5
E-2	60	0	7 5
B-4	56	8	7 0
B-5	60	10	6 0
D-3	65	12	5 4
C-7	75	14	5.4
A-3	64	12	5.3
B-6	62	12	5.2



WIND RESISTANCE OF SHELTER-BELT PARA 12-30.

FIGURE 46.

The Prairie States Forestry Project started in 1934, when I had the privilege of seeing some of this work in North Dakota. Its object was to provide the arid Middle Western States with an elaborate series of shelter-belts, and a recent summary (E. N. Munns and J. H. Stoeckeler in *Jour. For.*, April 1946) shows how this has succeeded beyond even the dreams of the most optimistic, and in face of probably the most severe criticism and opposition which any forestry project has ever met. To date nearly 19,000 miles of belt have been established on 33,000 farms; 78% of the entire belts are rated as fully effective and only 10% as unsatisfactory. The rainfall of the area is 16 to 30 inches and in this respect is rather better than our desert fringe, but on the other hand we have less frost and no snow to contend with; growth rates are 30 to 50% better in the better rainfall zone; nearly all were a multiple of species of tree and shrub in at least 20 rows; broadleaf species have done better than conifers, although two juniper species have done well. The broadleaf species close their canopy quicker, and emphasis is placed on quick closing of the

canopy because intercultivation is essential until that has happened. With a 10 ft. spacing giving closure in 6 years, a year is lost for each additional foot added to the spacing. Failures are almost entirely due to neglect of intercultivation by the farmer owners, but to an even greater extent to their allowing browsing by cattle and horses, particularly when the larger trees are out of danger and there appears to be little harm in allowing a few animals in. It is generally admitted that farm crops do badly in the immediate shade of the belt, but this is far more than compensated by the large area of crops beyond which benefit by the shelter. Most farmers have only one side of each 80 acre or 160 acre block planted—i.e. every 2 to 3 furlongs apart, but where fruit gardens are established shelter is needed for every 5 to 20 acres. For *kana* grass alone on 2 ft. high bunds 80—100 ft. apart is recommended, and for trees with or without *kana* grass 200—400 ft. apart for belts of from one to 8 rows deep.

12. 30. Russian experience shows that tree shelter-belts with 8 rows of trees in a width of 10.5 metres (34 yards) and a height of 17 metres reduce wind velocity by 20% over one kilometre (5|8 mile) when the wind on open prairie has a velocity of 2.5 to 3 metres per second, and by 30% with a wind of 5.5 metres per second. The drier the weather the more marked is the ameliorating effect of the belt upon temperature and evaporation. Evaporation is reduced 17 to 25% over a width 60 times the height of the trees for a 2.5 to 3 metre per second wind and over an even wider belt upto 100 times the height for higher velocities. The Russian Institute of Silviculture and Improvement of Farmland by Afforestation at Rostashi, which produced these data, advises that a certain amount of penetrability by wind is desirable as a slight movement of wind serves to keep the upper dry air masses from descending to lower protected levels. There thus appears to be no special virtue in a dense mass of woodland, and belts with from 3 to 8 rows of trees are recommended by both Russian and American workers. (*U. S. Forest Service Division of Silvics Translation No.* 164; 1935).

Height alone is only of value provided the belt as a whole presents a more or less complete front to the wind, thus a single row of tall trees with bare trunks and wide gaps in the lower part of the windwall will obviously allow a lot of wind through, and the objective should be to build up from the ground, using whatever local species will form a resistant windwall. This of course need not be all in the same row as the tallest trees, and in fact a better windwall is formed by having the ground-level shrubs to windward, the small tree species in the middle, and the tallest species to leaward. In New Zealand trees 66 ft. high give full protection

for a strip 350 ft. broad and partial protection for 1000 ft.; thus well spaced tree belts with intermediate belts of low dense hedges are recommended (P.S. Sym in *New Zealand Jour. Agri. No.* 68 of 1944) and this latter is the counterpart of my *sirkanda* proposals. Even annuals are of value to increase wind resistance on the lowest windward face. Bushes bearing edible fruits should be encouraged such as *Capparis aphylla* & *Zizyphus* spp.

The wider implications of amenity and cultural value of trees must constantly be taught along with constant reiteration of the technique of dry zone planting and will be needed for many years before the inhabitants of our desert fringe districts can be trusted to look after their own shelter-belts properly. *Forestry Abstracts* VI-3 of 1945 contains a useful list of references to shelter-belt literature compiled by A. H. Weir.

12. 31. *Planting Sand Dunes and Sandy Contour Bunds.*—The secret of successful planting of land rendered unstable by wind erosion lies in:—(a) moisture conservation in the deeper layers and (b) protecting the roots of the young plant from exposure through the soil being blown out from underneath it. The technique of contouring to conserve moisture has been fully dealt with in Chapter III. Planting practice must concentrate upon anchoring the top sand until the plants can become fully established. In the case of shallow-rooted species such as *sirkanda* grass, it may pay to anchor the surface down by spreading a mulch of cut grass or branches over it and between the plants, but such a cover is itself liable to be blown away or at least rolled up in heaps by the wind unless it is pegged down. A criss-cross pattern of branches knitted into bundles and planted upright gives good protection to young plants.

In the case of tree species such as pines whose roots are somewhat tender, pot plants in long tubes of tin or pottery (such as are used in the Changa Manga method for transplanting eucalyptus) will allow the plants to adjust themselves gradually to the sand. For species such as *sissoo* or any others which will grow from root and shoot cuttings, the root portion should be cut as long as possible and buried deeply in the planting site. In the case of direct sowings the sown patches should be fully protected with brushwood hurdles well pegged down to windward of each pach. (Figures 21 and 22).

12. 32. *Dry Farming Technique.*—This must be fully understood by all foresters working upon shelterbelt afforestation or the improvement of arid zone pastures, so is dealt with here in some detail. The first consideration in the *barani* cultivation of crops in desert fringe districts is the storage of water in the

soil. The bulk of the annual precipitation occurs during one period of two months (July and August) the remaining months being one long dry period possibly relieved by light falls of rain during December and January. The monsoon in the desert fringe is short and erratic, it may consist of only 2 or 3 short but heavy showers. The storage of water in *barani* land is therefore vital. The time of first ploughing is of the utmost importance because the tilth produced is almost wholly dependent on this. The land must be ploughed when in a friable condition (the condition described in Punjabi by the word *wattar*). If *it is ploughed too dry or too wet, it will be found to break into* large clods which, particularly when irrigation is non-existent, will take much time and labour to reduce to a tilth. The ideal size of the *soil crumbs* depends upon the type of soil (being larger the greater the clay content), but they should readily break up under pressure between the fingers and thumb. The best time to plough to obtain this tilth is usually immediately after any heavy shower.

Levelling.—The first essential in dry farming is to have level fields. Whenever land is uneven it should be levelled up, and terraced where necessary. The area should be divided into compartments of the same level, each fully bunded.

Small kiaras and bunds.—The bunds along the boundary of each small field should be strong, permanent and at least a foot high. The fields, while lying fallow, may be divided into small compartments to retain in them all possible rainfall. The bunds for compartments can be easily made by means of a furrow-turning plough or a *karah* scoop.

12. 33. The *rotation* usually followed in the eastern Punjab is *rabi-kharif*-fallow-fallow. For this purpose the total area of the holding should be divided into two parts, so that in one year, while one half is under the *rabi* and *kharif* crops, the other half is lying fallow. In areas of very low rainfall it is better to leave a portion of the holding to lie fallow for two years in case sufficient moisture has not been collected in it during its fallow of one year only. This is approximately the same as the common Bijapur practice of ploughing only a third of the area each year.

12. 34. Preliminary cultivation of the land should begin immediately the land is free from the previous crop. But in areas of exceptionally low rainfall, or areas which are subject to hot winds, e.g., most of the south-east Punjab, or all the western uplands, *in the pre-monsoon period ploughing or otherwise stirring of the soil may be actually harmful* as it is liable to aggravate erosion by wind. The safest way, therefore would be to open up the land with the first monsoon shower. Preliminary cultivation is

best done by ploughing deep by means of a furrow-turning plough.

Within reasonable limits, the finer the subdivision of the soil, the greater is its capacity for the storage of water, but the greater also is the danger of its blowing away. A deep loose fine soil should be overlaid by a dry surface mulch of larger soil crumbs through which stored water cannot be lost through evaporation. The effect of subsequent cultivations should be that the clods left by the plough are disturbed by movement, fine particles being broken off and sifted to the bottom of the ploughed layer. The original clod, reduced in size by each cultivation, would be left on the surface. Thus by constant cultivation a loose fine layer would be built up from below, getting deeper and deeper with each cultivation. If all cultivations are made to the same depth, not only are they of no value, but by disturbing this layer of fine soil underlying the clods, it is deprived of any water it may contain. No fallow is of value which is not clean; a crop of weeds will take just as much food and water from a soil as a useful crop. Early and constant cultivation of a weedy fallow is therefore essential in order to get rid of the weeds before further water is stored in it.

If, however the soil is too hard to be opened up by means of a furrow-turning plough, it should first be scratched on the surface by means of a *desi* plough (local plough with a long *phali* used in the south-east Punjab) or a cultivator or disc harrow, and after the surface of the soil has been scratched in this way (worked twice if necessary) the land will then be opened up by means of a furrow-turning plough. After the land has been ploughed it should be left as it is to await further rain, making sure that the boundary bunds are secure, so that all rain water which falls will be retained in the land.

12. 35. *Final cultivation of the seed bed.*—After the cessation of rains in September it is time for the final cultivation of the land for *rabi* crops. In order to produce a proper seed bed, repeated stirring by means of a cultivator will be required. Constant harrowing afterwards will pulverize the soil and bring it nearer to the stage for the preparation of the final seed bed. The seed bed should be moist, deep, firm and fine. A layer of about 3 inches of fine earth should be on the top of moist earth underneath. At least three inches mulch is necessary in order to prevent loss of moisture. In case the mulch is too shallow, moisture from the moist soil beneath will be lost and fall too far below the field moisture capacity for seed sowing purposes. Sowing should be done so as to place the seed below the dry mulch immediately on the surface of the firm soil beneath.

Before starting actual sowing operations, it is always advisable to *sohaga* the land in order to secure clean furrows, but the use of the roller, clod-crusher or *sohaga* on *barani* land, unless followed immediately by a harrow, is greatly to be deprecated because it destroys the mulch and has much the same effect in causing loss of soil water as does the formation of crust after rain.

Harrowing by means of a bar harrow is useful to keep down weeds and also to maintain a mulch on the surface to prevent evaporation of soil moisture. The lever harrow is an even better implement for this purpose than a bar because the depth to which the tines of the harrow should penetrate the soil can be adjusted in the lever harrow, which is not the case in the bar harrow.

12. 36. The maintenance of the fallow is often sadly neglected. The recent increase of *pohli* and other weeds on fallow lands, and the neglect of bunds allowing breaches to drain off moisture which should have seeped into the soil, are too common. There are three dangers to avoid:—firstly, loss of soil water and plant food due to the growth of weeds; secondly, loss of soil water due to the destruction of the dry mulch on the surface; and thirdly the loss of water through failure to maintain bunds in good order. Provided weeds are not allowed to establish themselves, the spring-tooth harrow set to the depth of the dry soil mulch will be sufficient to clean the fallow, whilst the same implement used to the same depth will maintain the dry soil mulch if used after every shower of rain.

12. 37. *Clean fallow versus cover crops.*—The insistence of the orthodox farmer on a clean fallow kept free of weeds and in an absorptive condition appears to conflict with any recommendations for covering the uncropped land with a plant cover which will reduce surface soil wash and help to build up a better humus content. The one saving must be balanced against the other, and it is only when sheet or wind erosion is very serious that the protective value of a cover crop outweighs the urgent need for moisture. In practice therefore we must first demonstrate in our conservation practice that whatever we recommend in the way of cover crops does not conflict with the essential need of the desert fringe, namely water conservation in every field. The value of cover crops becomes more obvious where the rainfall is normally enough to support such vegetation as well as the farmer's crop. By good water conservation in every field we can bring cover crops into use in areas appreciably nearer desert conditions, and thereby help to build up a better soil fertility. When possible, therefore, green manuring rather than the production of fodder crops is to be advocated, and the production of *kharif* fodder crops is not advisable. Such crops as *juar*,

maize and *bajra* make heavy demands on stores of plant nutrients and transpire more water per lb. of dry matter produced that any *rabi* crop it is possible to grow on *barani* land in this country. On the other hand trials in the dry zone of Ceylon with growing Napier grass taking the place of bare fallow showed that appreciable increases in organic matter and nitrogen resulted and that the physical condition of the soil was markedly improved. (Joachim, A. W. R. and Kandiah, S. in *Trop. Agric.*, Vol. 100, No. 2).

12. 38. If fodder crops as such must be grown it is better to keep to finer-leaved *rabi* crops such as gram, oats, barley or wheat and lift the crop before the grain begins to form. Of the *kharif* fodder crops the best for soil improving is *guara* (field vetch, *Cyamopsis psoralioides*), either pure or mixed with *juar*. When used pure it need not be manured but on the other hand Mr. C. H. Parr's experiments at the Imperial Agricultural Research Institute New Delhi farm show clearly that any manures given to this crop will also benefit the subsequent *rabi* crop on the same land. *Guara* is sown 25 lb. per acre if pure and 15 lbs. if sown with *juar*, and will yield a good crop of green fodder two months after sowing provided there are well distributed monsoon showers.

12. 39. Where bare fallow is still the practice and the individual fields are large enough to justify the use of mechanical equipment, an exceedingly useful tool is the *basin-lister*, which is a double or triple digging scoop drawn by a wheeled tractor. It digs out a series of shallow trenches 10 ft. long by 3 ft. wide and 1 ft. deep, thus pitting the entire surface of the field. To quote only one instance of its usefulness:—Two comparable fields at Hays Kansas, on a 5% slope received a 2½ inch rainfall in 30 minutes; one field pitted by this basin-lister gave no run-off whatever while the adjoining field with a flat pulverised surface yielded 68% of the rain as run-off carrying 17 tons of soil per acre. (Trade pamphlet issued by International Harvester Co.). Such an equipment would be of the utmost value in the arid zone of the Punjab where every drop of rain is of importance to the farmer, particularly in securing a good moist seed bed at the close of the monsoon.

12. 40. *Wild Leguminous Bushes as Cover Crops on fallow.*—The use of a green crop, preferably leguminous, for growing on fallow land in order to protect it from wind and sheet erosion, and which in due course can be ploughed under to build up a body of humus, has reached its best Indian development in Madras. It is most readily successful with irrigation or a good rainfall, because the green manure thus ploughed in is of little

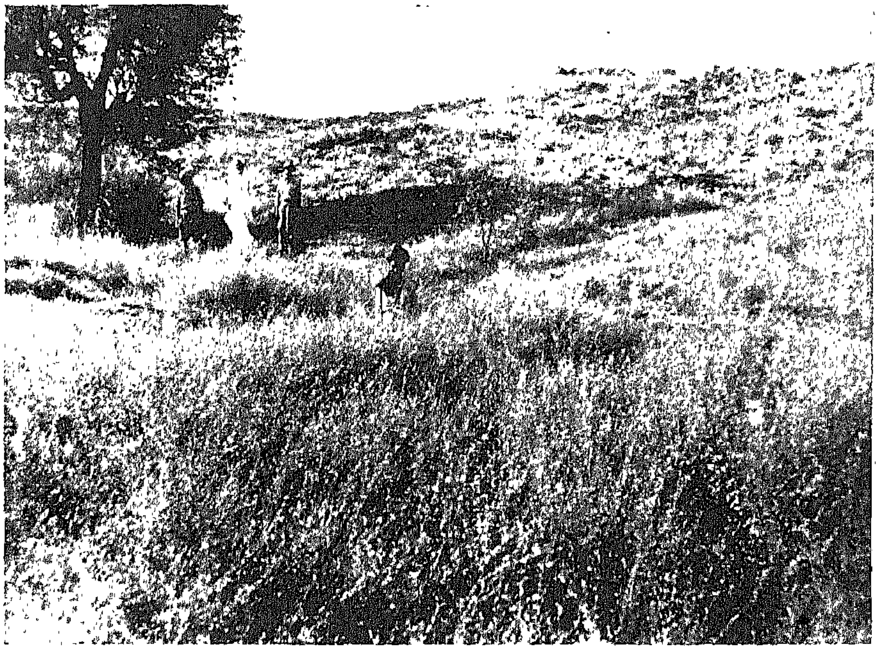


PLATE 24 (i)

One season's volunteer growth of *Indigofera paucifolia* (*khip*) in what was previously a completely bare nala bed in Nowshera near Pindigheb, as a result of one season's closure and gully plugging.—Para 12.40.

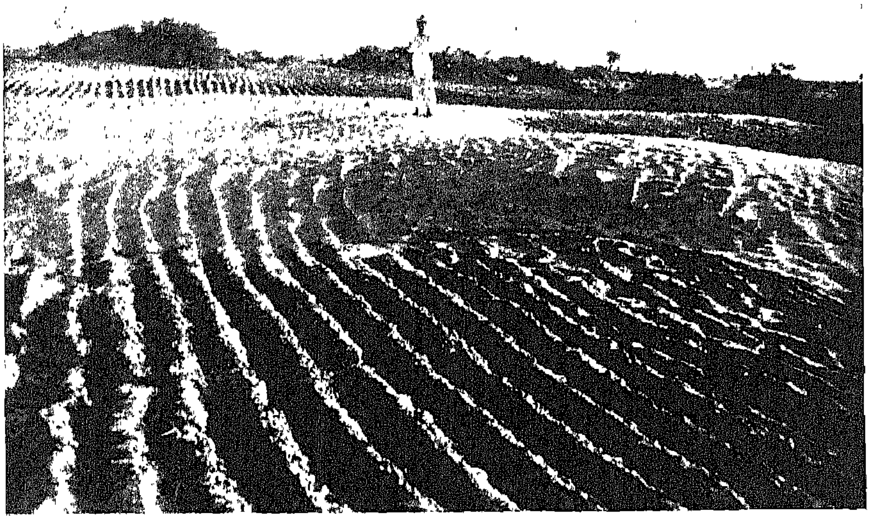


PLATE 24 (ii)

Sand blowing into plough furrows in Ferozepur district indicating the urgent necessity of shelterbelts, the only means of stopping this menace.—Para 12.14.

use to the next crop until it has been rotted down. In dry zone farming it is apt to lie unrotted, and in this condition it is liable to depress rather than improve the performance of the next crop.

In the use of green manures the main essentials are:—(a) quick production of a large bulk of vegetable fibre, (b) quick rotting of this fibre, (c) moisture storage, first for the green crop itself, and secondly for the subsequent crop it is intended to help.

There is a great dearth of leguminous crops which will fulfil these requirements in our low rainfall zone, because none of the usual fodders such as *berseem* or *mehti*, or the *sunn* hemp which is the commonest green manure, will succeed without good moisture conditions. *Guara* is the best of the orthodox green manure plants, and its use should be widely publicised amongst the cultivators.

12. 41. There are great possibilities so far undeveloped in India for the use of wild leguminous bushes, such as the *Crotolarias, Lespedezas*, and *Dalea* clover now widely used in the U.S.A. Similar plants of the Punjab which should be given extensive trials are:—

Crotolaria burhia (Salt Range).

Sesbania aegyptica—jaint, a common hedge plant.

Indigofera paucifolia—the *kathi* or *kainthi* or *khip* of the S. W. dry plains.

Tephrosia purpurea (foothills).

Psoralia spp—a camel browse in Hissar.

Both of these are reported from Bombay as being useful green fodder and green manure plants.

Alhagi camelorum—the *jousa* camel thorn of the Salt Range.

Lespedeza sericea—scattered in Kangra and the foothills generally, but has been bred as a crop plant in U.S.A.

Atylosia scarabioides (Hoshiarpur Siwaliks & Nurpur, Kangra).

Sophora griffithii (Salt Range and Trans-Indus).

Taverniera nummularia (*mattu* in Kangra, *riari* in Rawalpindi).

Argyrolobium roseum (Nurpur, Kangra).

12. 42. All bare fallow land is in constant danger from sheet-wash, and also from wind erosion, and it is for this very reason that we are trying to find some plant which can be sown

by the farmer either along with his crop, or when he cuts that crop; the requisites of this plant are:—(i) to form a ground cover to protect the soil against erosion; (ii) it should preferably be leguminous so that it will itself enrich the soil by building up the nitrogen content; (iii) its seed must be plentiful and cheap; (iv) it must be easily eradicated by ploughing under, or if it reseeds quickly it must not be so rampant as to interfere with the next crop; (v) it should be in leaf at the beginning of the monsoon to give the soil maximum protection; (vi) it should preferably be a fodder plant. The Americans found various *Lespedezas* growing wild which had those characteristics and have bred them until they now form a recognised crop, chiefly *L. sericea* which incidentally yields a good alternative fodder.

12. 43. *Lespedeza sericea* and *juncea* are both perennials and have been much used in the U.S.A. after some years of intensive breeding work. Many strains are now separated, mostly for use on badly eroded land where gullies are actually forming and also for producing a dense plant mat on field drainage ways. It is cut as a hay and fed to livestock, and forms a useful plant to attract game birds such as quail. Several *Lespedezas* including both of the above and *L. gerardiana* are quite common in the Himalayan chir and oak belt and *L. stenocarpa* on the plains, but none of them appear to be gregarious or heavy seeders, so it would be advisable to get imported American seed from any of the hot Southern States for extensive trials in our soil conservation districts.

12. 44. The Kudzu vine (*Pueraria thunbergiana*) has been much publicised and has produced amazing results as a preventer of erosion in the gullied lands of Florida and other Southern States in the U.S.A. but attempts to get it established in the Punjab have so far failed. In 1937 some plants were obtained by the Agriculture Department and transplanted in Kangra, but the site chosen was hot and dry and the plants were not protected from grazing so they did not survive. A few individual plants are to be found in gardens in the Punjab but are nowhere robust. C. H. Parr reports promising results with it on the I.A.R.I. Farm, New Delhi. The Bombay Agriculture and Forest Departments and also Prof. N. V. Joshi at the Ferguson College, Poona, are all working on its propagation; even in the U.S.A. it does not seed freely and has to be propagated by layering. Several closely allied *Puerarias* are common in the moister parts of India and *P. tuberosa* is used as a fodder in the Simla hills but is nowhere very common.

12. 45. In the Ceylon tea or rubber estates many years of research have failed to find a suitable leguminous plant, though

for certain restricted areas *Indigofera entdecaphylla* has proved useful, and they are now trying to sort out their non-leguminous weeds into desirable and undesirable in a system of "selective weeding." This is mentioned here to show the difficulties yet to be solved. The right answer appears to lie amongst the bushy *Indigofera* species, several of which occur on waste land in different districts of the Western Punjab, seed fairly heavily, and can be used as a chopped fodder. For example, *Indigofera paucifolia* and some other unidentified *Indigoferas* occur commonly in Attock and the less disturbed low dunes of the Mianwali Thal. It should be fairly easy to harvest and establish one or other of these for sowing on fallow. In the moister Eastern districts the choice is much wider and trials should include *Lespedeza sericea* of the Siwaliks, though as far as observations go, this does not seed nearly so profusely as either *Indigofera gerardiana* and *dosua*; *Desmodium tiliaefolium*, and *Taverniera nummularia* which is rampant on certain Kangra landslips. A collection of leguminous components in the Nurpur (Kangra) closures on badly eroded slopes showed a surprising variety of leguminous plants, which were identified by Silva's research workers in 1937 as having become invasive ahead of the grass crop which has since re-established itself. Some of these (listed para. 12. 41) should be worth further study. The cultivated pulses might also be used, but they are rather too fugitive during the hot weather and do not provide much of a cover at the beginning of the monsoon. Sir Edward Cole of the Coleyana estate brought seeds of subterranean and wild white clovers from Australia and tried them on his Punjab farm, but as these did not seed there, seeding trials were conducted in Kashmir and Ootacamund. Seed produced in the latter place is used for re-sowing. Similar difficulties have been experienced in obtaining fertile seed of *berseem* which it was thought could not produce fertile seed readily in the Punjab although it does in N.W.F.P., but is now being produced in Hissar.

Chapter XIII.

CO-ORDINATION.

13. 1. *Evidences of deterioration.*—Much literature exists which explains in general terms the effect of disforestation or the destruction of plant cover on the behaviour of rivers, but there is comparatively little relating to India showing any direct evidence of increase in flood intensity, decrease in dry weather supplies and increase in the burden of silt carried. Many writers have quoted soil erosion as being the main reason for the decay and disappearance of ancient civilisations such as the irrigation works of Mesopotamia, the hill terrace cultivation of the Negeb of Palestine, and the kingdom of the Incas of Central America.

13. 2. Although opinions differ as to how far forests affect the actual quantity and distribution of rainfall, it is generally accepted that destruction of plant cover does increase the run-off, and by exposing the surface soil produces an accumulative effect. This results in a shortening of the period of high flood and increase in the river potentiality for damage, and at the other end decrease in its dry season flow. The official opinion of the Meteorological Department is that although the influence of forests on actual rainfall is small, forests do by regulating the surface and subsoil moisture, flatten out the flood peaks in all streams and prolong the duration of the flow. The Central Board of Irrigation supports this and points to the detrimental effects already noticed in some of the smaller river basins such as the Ravi and the Uhl. The effect of destruction and deterioration in the plant cover is not immediately appreciable, but the ultimate result is disastrous and is not readily repairable. By the time the evidence is complete the chance of reversing the process is remote because by then much of the hill catchments will have been reduced to stony screes. It is therefore the duty of the present generation to safeguard the interests of the future which inevitably holds a heavy burden of excess population and economic pressure on the land.

13. 3. The United States of America is now suffering from the effects of recent denudation and since 1933 vast sums of money have been expended in trying to reverse the processes of desiccation and erosion. Much of this work has already produced good dividends in terms of prosperous farms, stable river

regimes a reduction in the severity of dust storms, a better co-ordination of farming practices and a more intelligent use of the land. India can therefore safely follow the lead thus given, for although the two countries are so obviously unlike in many ways, India having a very old history as compared with America's very recent one in terms of land utilization, there is a surprising similarity in many of our common problems.

13. 4. *Objects and Factors of Management.*—The objects of the Soil Conservation Service which forms a branch of the United States Department of Agriculture are stated as follows:—

"1. To determine the effect of erosion control practices and land use upon the conservation of water for agricultural purposes, such as irrigation and domestic farm supplies, and for public utility purposes, such as water power and urban water supplies.

2. To determine the effect of erosion control practices and land use upon the control of floods that destroy crops, damage soil fertility on agricultural lands, and cause damage to or destruction of municipal property.

3. To determine the rates and amounts of run-off and eroded soil material from rains of different amounts and intensities, for use in the economic design of erosion control and flood control structure. This information will also be of value in determining to what extent eroded material can be prevented from entering, and reducing the capacity of, drainage channels and reservoirs, by the application of proper land use and erosion control practices."

13. 5. The factors to be considered have been summarised as follows:—

"1. *Physical characteristics of river catchments.*

(a) soil and subsoil, including texture, structure, composition, and degree of saturation.

(b) topography, that is, degree and length of slopes, and uniformity and regularity of ground surface across and along slopes.

(c) physiography, including arrangement of drainage systems.

(d) cover, that is, forest, pasture, and cultivated and other crops.

(e) storage, that is, surface and underground.

(f) artificial factors, that is, tillage practices and erosion control practices.

(g) geological formation.

2. *Precipitation.*

a. Amount.

b. Intensity.

c. Duration.

d. Distribution, that is, over watershed, and seasonal.

3. *Water disposal.*

a. Evaporation.

b. Percolation, including ground water reaching streams and deep seepage, that is, water not appearing again in drainage channels of watershed.

c. Interception and transpiration.

d. Surface run-off.

In addition to measurements and studies of the foregoing factors, continuous records will be kept and studies made of the direction and velocity of wind, humidity, air and soil temperatures, and atmospheric pressure."

These factors are of course equally applicable to India and it is for considerable how far the American technique based on the accumulation of vast quantities of data collected from intensive recording is justified. The immediate necessity is for a rough survey of erosion conditions and land use in the catchment areas themselves, starting with those to which a definite priority already attaches through having been selected for major irrigation, high dam or hydro-electric projects.

13. 6. *Outline of large scale demonstration projects for a whole catchment or region.*—In his report on the work of the Imperial Council of Agricultural Research in applying science to crop production in India, Sir John Russell makes the followin remarks:—

"In dealing with soil erosion the need is for more action rather than more research . . . . I see no point in spending time and money on approaching the subject from the laboratory end; the problem is in the field and there it should be worked out."

The way in which this line of work was first followed up in America is given in detail in my *Use and Misuse of Land*

(Oxford Forestry Memoir No. 19, 1935). In October 1933 Dr. H. H. Bennett was asked to select a number of watersheds, each about 100,000 to 200,000 acres in area, and undertake to establish as far as possible in those areas such types of erosion control and land use as would be effective in materially reducing soil and water losses. It was intended that these watersheds should serve as proving grounds or demonstrations of what might be done to check erosion damage to farm and range lands; to reduce the load of silt being deposited in streams and reservoirs; and, in addition, to serve as a measure in the control of floods. Later this activity was transferred from the Department of the Interior to the Department of Agriculture which in the U.S.A. comprises a number of branches including the Forest Service and the Soil Conservation Service as well as the various activities of agriculture "extension" and research. The original principle of area demonstrations on a watershed basis has been continued, although the size of a demonstration area has been reduced to about 25,000 acres in order to provide for a wider application of the plan to a greater number of sections of the United States in need of such treatment." There are now 25 such demonstration projects throughout the U.S.A. These are not to be confused with the *soil conservation districts* which are a later development and have a different structure and function. An area becomes a "district" when a majority of the owners and occupiers vote for it to be brought under the Land Conservation Act after which a small management board is given very full powers of enforcement.

In India there should be in each province suffering from erosion a demonstration project on a really large scale for each major region or recognisable problem area. It will be seen that the size of the American "project" was originally intended to be 100,000 to 200,000 acres i.e., 156 to 312 sq. miles but that it was reduced to an average of 25,000 acres i.e., 39 sq. miles each. For India, it would probably be best to err on the side of largeness of project area. If real progress is to be made, each area should be of a size that would give whole time occupation to a first class officer and staff, and should be about 70,000 acres as a minimum (just over 100 sq. miles). Whatever its size each area, selected would be one having natural physiographic boundaries, where erosion is a problem of importance and which is easily accessible. An area of the type envisaged might be, for example, one containing a line of hills with two projecting spurs, between which there is a natural drainage basin containing the beginning of a river and its tributaries. The hills would probably contain some type of tree growth and grassland gradually merging into cultivated ground on the lower slopes and the

succeeding flat land. Erosion would probably be represented by gullies at the base of the slope spreading out into broader patterns in the cultivated ground and accompanied by sheet erosion in the upper slopes and flat areas. Another type of area suitable for such a project might be one in which gullies or bank erosion cut back into good land along the banks of the large *rivers, like the Jumna or the Indus.*

13. 8. In a large scale anti-erosion project, the first step would naturally be a survey in which all existing maps would be used and a new special map made of the area. In the *American projects an* aerial photographic map of 8 miles to the inch is made and an aerial map should be regarded as a necessity for similar work in India. (Fig. 47 and Plate 27.) Such work can be carried out either by contract with one of the companies which undertake this work or as an exercise for the aerial photographic staff of the R.A.F. Our mosaics of parts of Rawalpindi, Attock and Jhelum cost roughly 400|- a square mile. The next step would be the planning of the various measures to be taken in the various parts of the area and at different times. In the American project the first 2 to 2½ years are used for survey and construction and the final 3 or 2½ years for maintenance, the whole project being regarded as a 5 year scheme. This rate of progress is impossible in India, and we should double the time for each phase of the scheme and its total duration, i.e., it should be a ten years' scheme. The following are a certain number of measures which would be required in the various places and at various stages:—

a. Re-afforestation.

b. Controlled grazing and active improvement of grass-lands by grass cultivation and introducing rotations.

c. Gully-plugging of selected torrents.

d. Terracing and wattbandi of fields.

e. Making of grassed waterways and masonry escapes.

f. Hedge planting on contoured boundaries after consolidation of holdings.

g. Stream canalisation and diversion.

h. Making of soaking compartments to take up diverted water.

i. The introduction of certain new agricultural practices such as basin listing and strip-cropping.

j. Opportunity should be taken to form Better Farming Societies, Stock Breeding Societies, Societies for Consolidation of Holdings and for the reclamation of commons and ravined lands.

k. Reduction of surplus livestock and encouragement of stall feeding.

13. 9. *Administration.*—Work on such a scale naturally involves considerable administrative arrangements. In the U. S. projects the co-operation is sought of the farmers of the area and formal agreements are made between the farmers and Government specifying what each party agrees to furnish with reference to materials, labour, equipment and technical assistance. The farmer performs all regular farming operations and also contributes additional labour in many cases. Government furnishes labour from the Civilian Conservation Camps and provides all the technical staff. In India, where conditions are so different, the procedure is altered in detail. The general lines of help however are the same i.e., it would be necessary for Government to provide free:—(a) technicians, (b) a good deal of the labour for the remodelling and re-construction work, (c) co-operative organisation.

13. 10. The main difficulty in carrying out such projects is the lack in India of men trained in such work, or who are conservation minded. We need first of all a forest or agricultural officer who can "see" what a remodelled countryside should look like, who has soaked himself in the Amercian and Indian literature on the subject, and who has had some practical experience, even on a small scale, of such work. He needs a competent surveying and engineering staff, the help of a revenue officer to make arrangements with the people, and an honest forest staff which will preserve closures faithfully as well as do all the tree and grass planting. To complete the team there should also be a cooperation specialist with training in the consolidation of holdings: a practical agriculturist who can advise on changes in crops and cultivation methods which may be rendered necessary by wattbandi; and a fodder expert who can teach the use of the wild fodder plants which become plentiful as a result of closures.

13. 11. *The Catchment a Natural Unit.*—Much information on the conditions in parts at least of our main catchments are already known to one or other of the forest, revenue, geological, meteorological and agriculture department, but no single authority can supply complete information for an entire river basin as regards slopes, plant cover, rainfall and land uses. Since the catchment areas of almost all the important Indian rivers extend beyond British India into Baluchistan, Afghanistan, Tibet, Kashmir and many other Indian states, complete investigations cannot be done by a purely provincial authority, but this must not be used as an excuse for failing to organise our efforts within the province to the highest degree possible.

13. 12. "A national government, broadly speaking, should handle a country's external affairs, and all internal questions which are common to the whole country. The ideal local government should handle completely, and from beginning to end, the maximum of problems affecting its area and population. It should be able to do this without interference with, or from, any other local government, for the good of its own population, and without affecting anyone else. There is one, and only one, topographical unit which is self-contained and in which these problems can be solved completely, and that is the watershed of a river. It is the home of many works and services in their entirety, including arterial drainage and flood prevention, hydro-electric and other power, water supply, sewerage, sewage disposal, fishery conservation, river crossings—(bridges, tunnels, ferries)—ports, and inland water transport. The methods adopted to deal with these matters can affect no one outside the watershed but will affect directly or indirectly, everyone of its inhabitants. A river from source to sea is one organic whole. and any work done on a section of it will affect its whole regime. Its watershed is thus the smallest area in which proper planning —complete and long-term planning—can be carried out, and it is therefore imperative that one regional authority should control its entire area, with possibly sub-authorities in charge of the tributary watersheds. To entrust a piece of the planning of these interlocked problems to each of a number of smaller authorities would be equivalent to sending an army into battle and allowing each platoon to select its own starting point, zero hour, and objective." (C. G. Lynam, O.B.E., M. I. Struct. E. "Watersheds and Local Governments" in *Engineering* for 11 Aug. 1944).

13. 13. *Watersheds and Catchment Areas.*—Strictly speaking a catchment area or catchment basin is the entire area from which drainage is received by a river or a reservoir, while a watershed is the dividing ridge between two drainage areas. The American use of the word "watershed" has made it interchangeable with "catchment," and care must be used in reading technical papers to determine in which sense the word "watershed" is being used because this alternative use of the word is not confined to America.

13. 14. *Boundaries.*—The first principle in all soil conservation work must always be to start at the top. So the first thing to determine for any working area is the location of the watershed, in the strict sense. Political and civil boundaries are apt to follow river banks as boundaries, and it is seldom that a

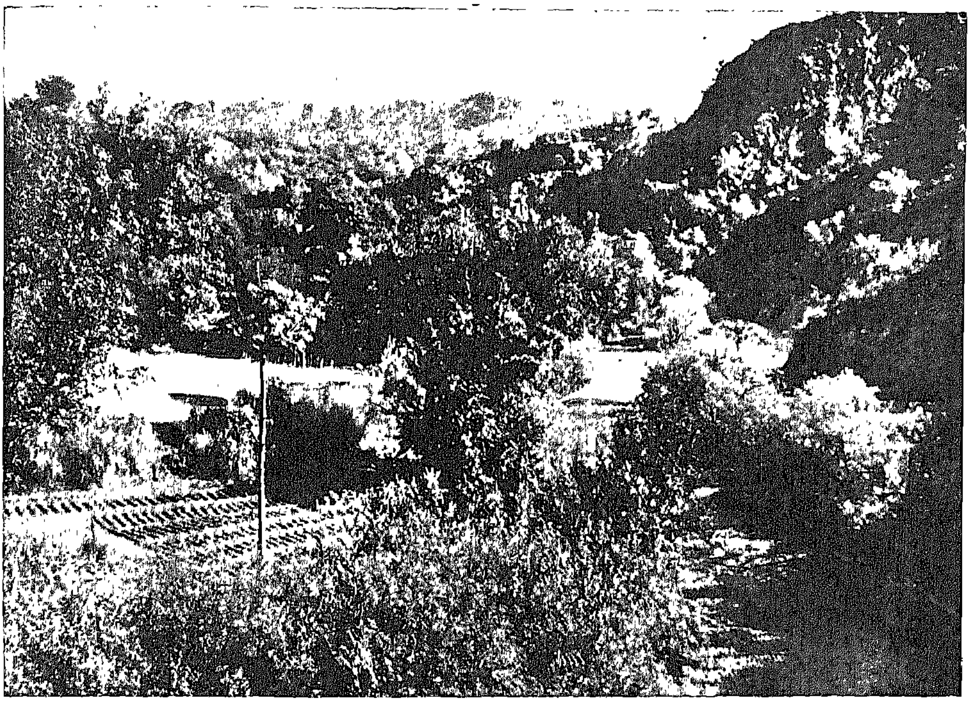


PLATE 25. (i)

The complete reclamation of this part of Chohal Cho bed within the hills has only become possible as a result of extensive & strict closure to grazing in the catchment behind: Para 13.13.

PLATE 25. (ii)

Some branches of Dholbaha Cho are showing a tendency towards perennial flow. The object of extensive gully-plugging in the upper reaches is to develop this further; Para 8.7.

major catchment falls wholly within one administration, hence the need for establishing a catchment board with overriding powers to ensure that the various administrations within a catchment carry out their obligations. The classic example for this is the Tennessee Valley Authority of 3 men who have been given very complete powers to enforce the federal government's programme of soil and water conservation, power, forestry, and farm improvement, education, welfare etc., in parts of 7 different self-governing states. A study of the technique employed not only in stopping erosion but also in the administrative problems will well repay study (J. S. Huxley's "TVA,—Adventure in Planning"; Architectural Press, Chean, Surrey, 1944, and D. E. Lilienthal's "TVA, Democracy on the March"; Penguin Special, 1944).

13. 15. *Central or Federal Action.*—A start has been made in India by the creation of a Central Water and Inland Navigation Committee at New Delhi (known as "Quink") but this and any boards appointed for specific catchments are likely to be purely advisory. Their work is likely to be influenced by the preparation of regional plans which will lay down the correct soil conservation technique and procedure for each major catchment as a unit irrespective of political boundaries, after which it will be the responsibility of the board concerned to see that the various political units follow the prescriptions of the plan. The formation of a Central Land Utilisation Board under the Government of India has been under consideration and it is hoped that amongst its functions will be the enforcement of prescriptions where political or other boundaries are causing failure. For each small catchment as in the case of each Siwalik cho, the Soil Conservation Circle can be relied upon to see that working plans are prepared as rapidly as can be for all areas now under conservation work, and ensure that any recalcitrant villages or groups holding out against the prescriptions of the plan are coerced into complying. This can best be done by applying one or other section of the Punjab Land Preservation Act 1944 (see Appendix II).

In view of the many proposals for the political sub-division of India it is interesting to note that M.W.M. Yeatts, C.I.E., in his *Census of India* 1941 propounded a 50 year plan for the development of water-power by dividing in India into 4 federal regions depending upon the natural physical divisions made by the catchments of the main rivers.

13. 16. *Preliminary Examination.*—For the larger catchments and particularly those with part outside the Punjab's

political control all known facts and data should be martialled so as to provide a picture of the meteorological conditions and the use and misuse of the land. Based on these facts, even when these are incomplete, a preliminary report should be prepared on the following points:—

(i) to determine whether flood damage is such as to warrant a more detailed flood control or erosion intensity survey.

(ii) to judge as to whether any elaborate programme of work is justified or feasible.

(iii) to locate as accurately as possible the source or origin within the catchment of rapid flooding and heavy silt.

(iv) a statement describing the general land use within the catchment and the effectiveness of simple closures to grazing as compared with more elaborate and extensive afforestation and engineering.

13. 17. *Detailed surveys.*—So far the Punjab practice has been for a forest officer to prepare a catchment plan, keeping very closely to the stereotyped forest working plan in both the framework in which it is written and the actual intentions and prescriptions. For small units such as a Kangra village society or a Hoshiarpur cho catchment this treatment is fairly satisfactory, provided its prescriptions include wholesale closure and elimination of grazing and browsing animals from those areas which are suffering most from erosion. For the larger catchments and particularly where Indian states are concerned this method of approach is unlikely to produce results. We are forced therefore to approach the problem on a wider front by producing a report shared by representatives of the other landholding departments and obtaining for their combined report the blessing of the Political Department as well as that of the chief administrator of the province.

13. 18. In American practice the field party on a typical survey includes a soil conservationist, an agronomist, a forester, a geologist, an irrigation or hydro-electric engineer, a rural economist and a farm management specialist. Appraisal of damage by floods and debris is covered by the geologist and the engineer, while the assessment of upland soil erosion and plant cover conditions is undertaken by the remainder working as a team. The frequency of future floods is estimated from whatever records of past floods and rainfall data are available. Plans

for altering harmful land use practices and ownership and tenancy customs are drawn up, finishing with a statement of costs of installing and maintaining this programme. 51 surveys covering about 300,000 sq. miles were authorised by the Secretary of Agriculture during 1938-1942.

13. 19. A preliminary organisation for Indian conditions will obviously require some modifications. The number of fully trained and experienced technicians in the professions enumerated is small indeed, and we must be content with a smaller team, so that officers with a superficial knowledge of more than one of these groups can be employed. The one essential for Indian conditions is an experienced revenue officer with a detailed knowledge of land-holding and tenancy practices, the method of assessment of land revenue payments and the operation of the existing local land revenue settlement and forest settlement procedure. Other essential knowledge is of consolidation of holdings, for the fragmentation of holdings is usually a serious stumbling block in any programme for improving the standard of cultivation. Similarly the possibilities for introducing co-operative societies or widening the scope of existing afforestation or reclamation societies to include better livestock and farm management must also be kept in view. These last 3 categories namely land revenue, consolidation and co-operation can generally be looked after by one experienced officer. (see also para. 13.10 above re agriculture and fodder experts).

13. 20. *Tenancy customs.*—Apart from the grazing problem the greatest single stumbling block which prevents progress is in the tenancy methods. The usual custom of *batai,* that is the landlord taking half the grain and allowing the tenant possession for only one crop, is responsible for much bad cultivation. There is no incentive to improve the field by terracing, levelling or wattbandi, and in fact improvement by the tenant himself is often followed by eviction and the land is given to another who can afford to pay a higher rent. This of course only happens with tenants-at-will (*ghair maurusi*). The more privileged class of occupancy (*maurusi*) tenants cannot be evicted except as a result of a civil suit, but in many districts the natural enmity between tenants and landlords discourages any effort by either to improve the land itself.

13. 21. *Co-operatives.*—There is thus a rich field for the improvement of farm land and farming practices by means of bringing these two antagonistic interests together under some form of co-operative organisation. This obviously includes the use of panchayats and of collective farming in the full-blooded Russian use of the term, but the simplest and most efficient line of approach is through the

co-operative department which constitutes a branch of the civil administration under a Registrar for the province and Assistant Registrars for each district. The great advantage of the co-operative organisation as already firmly established in the eastern Punjab is that technical officers who are concerned with land management and the operation of the regional plan in the field have the backing of an efficient office organisation. The co-operative department staff of Inspectors and Sub-Inspectors serves not only as a channel for persuading and educating the village members to the need for closures and better farming but they also handle the office work, office inspection, and the organisational side of society management.

13. 22. *Slope Classes.*—The Soil Conservation Service of the United States recognises four slope classes:—

Class A. Slopes requiring no particular erosion control measures other than proper crop management.

Class B. May be clean-tilled, but requires effective control measures.

Class C. Effective control of erosion is impracticable under clean-tilled crops; recommended for pasture, hay, or other close-growing crops.

Class D. Should not be cropped at all; but should be put under forest, or permanent grassland with grazing strictly controlled.

According to a bulletin of the Department of Agriculture, United States of America, in applying this classification to the Reedy Fork Demonstration area in North Carolina, the following ranges of gradient are commonly accepted as the limits of these several classes:—

Class A. 0 to 3 per cent, i.e., Level to 1 in 33.
Class B. 3 to 7 per cent; 1 in 33 to 1 in 14.
Class C. 7 to 12 per cent; 1 in 14 to 1 in 8½
Class D. Over 12 per cent; 1 in 8½ upwards.

13. 23. *Strip-cropping not useful for Punjab.*—Mr. Colin Maher, author of an article on strip-cropping in the *East African Agricultural Journal*, March, 1940, quotes the following American classification of slopes in connection with the recommendations for strip-cropping intervals. As already stated the average Punjabi *barani* field is not large enough to justify the elaborate sub-division of single fields under different crops but the classification is of value in indicating proper land use:—

"(a) Slopes 0 to 2 per cent. Minimum of 25 to 50 feet with erosion-resisting crops and 100 to 150 feet width maximum in row crops.

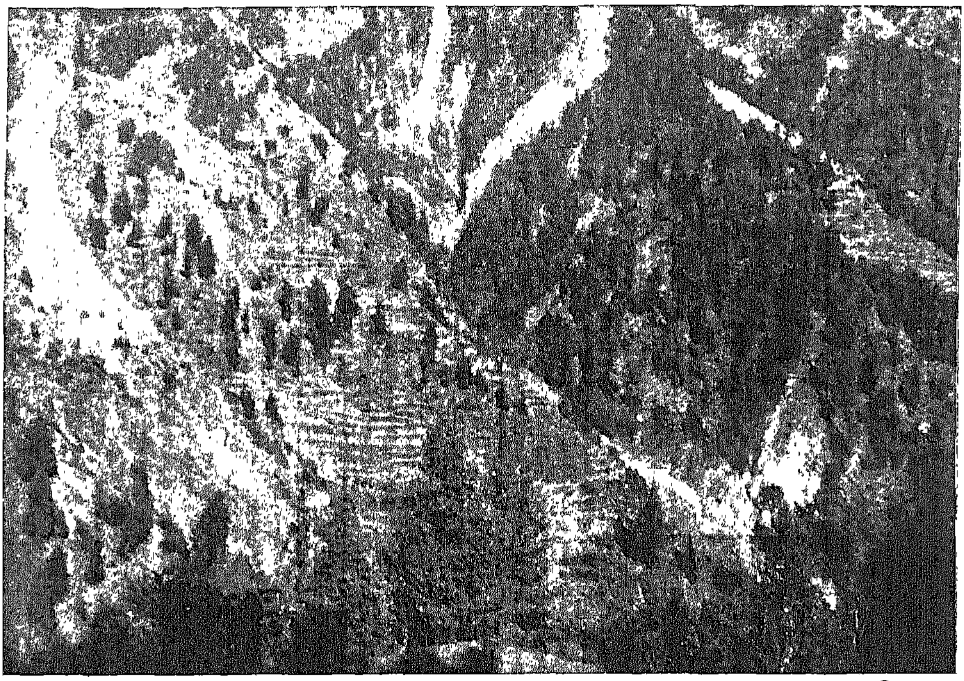


PLATE 29. (i)

Erosion intensity survey work in the Uhl valley necessitated mapping in terms of land use—e.g. land-slips, badly terraced cultivation, grazing grounds, & forest deteriorating can all be recognised here.

PLATE 29. (ii)

Erosion survey of Uhl in progress in 1936 vide Para. 13.24 (g)

(b) Slopes 2 per cent. to 3 per cent. Minimum of 40 to 50 feet in erosion-resisting crops and 75 to 125 feet maximum in row crops.

(c) Slopes too steep for terraces: Fifty per cent of the land area should be in a permanent or semi-permanent erosion-resistant crop.

No land with a slope of more than 12 per cent.—or 1 in 8½ gradient—should be brought under any form of cultivation; lands with a slope of more than 3 per cent. —or 1 in 33 gradient—are too steep for terracing."

America has not reached the stage of land starvation which we have, and there is a sufficiency of level or nearly level lands to meet the nation's requirements. If we adopt their standard, conservation of our hill land will be possible only by eliminating the human being! Mr. Maher's suggestion that some form of terrace would be practicable up to 10 per cent. or 12 per cent. slopes brings us nearer to what is suitable to us; in Punjab conditions with most of our unirrigated plains broken by undulations with greater slopes than 12 per cent., even this limit must remain an ideal. But in fixing the reserve gradient Government should not overlook the fact that other countries with greater knowledge than we have regard 3% as the highest gradient that allows land to be cultivated,—and that with a more regular distribution of rainfall than in the Punjab.

13. 24. *Instructions for Regional Classification and survey of Land.*

(a) To determine the correct use for waste and eroding lands, and to locate dangerous erosion in catchments being brought under a plan, surveys and reports should deal with the catchment area of one river or stream wherever possible, in order to ensure that the whole of the land which contributes to this river can be dealt with as a unit for control. Where topographical features are common to a series of catchments they can be dealt with under one and the same regional survey.

(b) Where this is not possible, as in the case of most Punjab plains and foothill districts, each tahsil should be reported on separately, but the report must link up with similar plans for adjoining areas to ensure that all land requiring attention is dealt with.

(c) The first step for each catchment|tahsil unit is to make a rough survey applying the following Land

Use Classification and allocating all ground to one or other of its ten classes. This classification is to be done on the basis of present ownership. Specific recommendations for change of ownership or of tenancy methods should be dealt with separately.

(d) This survey will yield a rough indication of the scale of the reclamatory or remedial work to be undertaken, and the amount of land which may have to be withdrawn from cultivation under classes V to VIII. Inclusion of land in classes III and IV is to give an indication that detailed schemes are needed. The officer making the Land Use Classification Survey is not expected to prepare detailed schemes within the tahsil unless he is specifically asked to do so.

(e) After these data have been collected the next step is to work out a detailed regional plan somewhat on the lines of a forest working plan but applying to all the various departments whose activities are involved.

(f) Where erosion conditions are severe, or where for some special reason such as run-off control in vitally important catchments (e.g., the Uhl and the proposed high dam at Bhakra, etc.) it may be essential to undertake a field-to-field survey of erosion conditions. This has so far been done only in one case, namely the Uhl.

(g) In the case of the Uhl the field-to-field survey was built up on a rather elaborate basis of numerical digits, each of which had some special significance in describing the condition of the land. The main classes were:—cultivation, forest, grassland, glaciers, screes. *Cultivation* was *sub-divided into permanent, periodic*, current fallow, abandoned etc., then into condition of terracing and crops used. Forest was sub-divided under type, condition of soil cover and condition of tree canopy. Grassland was sub-divided under village waste, private shamlat. alpine pastures, permanent use, seasonal use for grazing or grass-cutting, incidence and type of animal grazed.

Further digits were used to describe the angle of slope, the porosity of the soil, soil types, erosiveness of the top soil in terms of liability to wash away, and liability to landslips. As an example quoted from an actual map reference $-\frac{C\ 194}{38790}-$ means: village cultivation permanently but very badly terraced, under potato crop; angle of slope 30, porosity 80%, very friable and easily eroded

soil, but no danger of landslip (For further details see author's notes on Soil Erosion Survey in Uhl, *Ind. For.* 1936).

(h) For a less detailed field-to-field survey a local list of types and uses can readily be worked out for each region before the survey starts, somewhat on the following lines. The chief difficulty in mapping of land according to the attached ten classifications is to show sufficient detail—e.g., on a 1" or even a 4" map it is difficult to show that the narrow strip of steep land along the banks of a deep nala bed require different treatment from the flat cultivated land which forms the major portion of the ground around.

For district-wise mapping of erosion intensity it is probably only feasible to show 4 groups:—(a) entirely free from erosion; (b) sheet erosion or moderate gullying, (c) deeply ravined, (d) wind erosion.

13. 25. *Land Use Classification (adapted for Punjab conditions).*

A. *Land suitable for cultivation (already under cultivation or can be made cultivable).*

Class I.—Land that can be cultivated permanently and safely without the need of special practices or treatments other than manuring and simple crop rotations, and where commonly recognised good farming methods are actually being employed to such an extent as to secure the land from erosion. This includes irrigation areas which are free of *kallar* salts and are otherwise in good management.

Class II.—Land that requires only a very simple scheme of contouring with *wattbandi* or terracing to enable it to be cultivated with safety. This includes the large areas of very gentle gradient and good soil where only occasional terraces or bunds are needed and where natural channels can safely carry surplus drainage without gullying.

Class III.—Land that requires more complex and intensive control measures if it is to be cultivated safely and permanently. In addition to *wattbandi* and terracing these measures may include the building of retaining walls, the provision of *nakkas* (sills) to ensure against breaching of field bunds, and the provision of check-dams in the natural drainage channels to ensure that

they are able to deal with surplus run-off. This group also includes water-logged areas which require drainage schemes, also *kallar* and *thur* salt lands where intensive rice growing reclamation work is needed.

B. *Land not suitable for permanent cultivation.*

Class IV.—Land not suitable for cultivation unless:—

(i) where very fully protected by shelter-belts e.g., torrent channels, river banks, or

(ii) where only a proportion of the total can safely be under fields as in the desert fringe districts owing to fear of shifting sand unless frequent wind-breaks are provided, or

(iii) where a heavy grass fallow perhaps 4 years out of 8 or 10 is essential to improve tilth (example: drier uplands of Hoshiarpur and *barani* lands in arid plains districts).

(iv) where temporary cultivation is merely a step towards re-establishing forest (irrigation areas allotted for afforestation).

C. *Land not suitable for cultivation.*

This group includes all land that is too steep, too sandy or too salt to admit of ordinary farming, and would actually be most productive under grassland, woodland or water catchment management.

Class V.—Land that is not susceptible to deterioration if covered with permanent forest or grass. Although this land should not be cultivated at any time, it may be used for controlled grazing or village forest. This covers normal "village waste", but this is an objectionable term, for there should be *no waste land.*

Class VI.—Land that is moderately susceptible to deterioration even under permanent grass or trees. Although this land should not be cultivated at any time, it may be used as hay fields or as grazing land under strict rotation, or village forest with careful restrictions to prevent clear felling, and only after introducing special practices such as contour ridging or closure for reseeding. This includes the very large areas of sandy torrent bed now being taken up for afforestation.

Class VII.—Land that is highly susceptible to deterioration even under permanent grass or trees. This land must not be cultivated at any time nor should it be

used as grazing land at all. Example: steeper slopes of Dhauladhar, Kangra; Siwaliks in Hoshiarpur and Ambala; and Pabbi Hills in Gujrat.

Class VIII.—Land which is to be put out of further agricultural use intentionally by creation of reservoirs, ponds for livestock watering or fish culture, fuel reserves, major shelter-belts, wild animal and bird sanctuaries, roads, railways and canals with their accompanying forest strips, air landing strips. Example: Simla water catchment forest.

D. *Land not suitable for any productive use.*

Class IX.—Land not at present suitable for cultivation or for the production of any permanent vegetation, but which by drastic treatment could be made productive in terms of trees and grass if not cultivation. This includes "bad lands" in the extremes of gullying, water-logged land etc. Example: ravined lands at Gujar Khan and in Attock.

Class X.—Land which has been rendered completely and permanently unproductive e.g., glaciers, landslips, rock outcrops. Example: bare rock surfaces in Uhl catchment.

13. 26. *Soil Surveys.*—Detailed soil survey has not progressed sufficiently far to be of much use to us in disentangling the many types of soil of the Punjab uplands, including as they do both alluvium and the altered but uncompact shales, marls and sand-rocks of the underlying Siwalik and Murree beds, often jumbled up within short surface distances. Nor are the chemical values or genetical classifications sufficiently clear to justify more than a very elementary separation which may enable us to decide upon the correct land use. Strictly speaking all our work of afforestation, torrent bed reclamation, dry rakh improvement, and conservation of water for crop, tree and fodder production should be based on a soil survey, but in actual practice, and in the absence of detailed knowledge of soil types for each locality, we are forced to depend upon rather arbitrary decisions as to the *land use capability,* which falls into either *Actual* or *Potential* in each of the following:—

i. Cultivated; improvable in terms of terracing or promotion from *barani* to *chahi*, *nehri,* inundation or diversion of water.

ii. Pasture, grassland, grazing land; improvable in terms of control, rotation, or grass cultivation.

iii. Woodland; improvable in terms of regulated cutting and subordination of grazing interests to make it fully productive.

iv. Town and village sites, roads, railways etc. which obviously cannot be used for our purposes.

v. Waste land; a term which any civilised community ought to be ashamed to have in its vocabulary; there should be no such thing, for every piece of land not actually being put to productive use in one or other of the above four categories should be gone over at stated intervals by a responsible body of planners until this class has been eliminated altogether. Not until then should anyone boast of their soil conservation or co-operative activities.

What is required therefore is not a very elaborate classification of soil types as such, though where such information is already available it is of course exceedingly useful. A soils man will naturally classify each area in terms of purely soil characteristics and he should not be influenced unduly by the rest of the team discussing land uses as such. His first duty is the expert recognition of the varieties of soil as such. He must however bear in mind that whatever data he produces must be of use to the others who follow him or apply his data in determining land uses. In addition to the actual soil texture and profile, other qualities such as slope, stoniness, irregularities due to gullying, the depth available for root development, the nature of the plant cover, the susceptibility to erosion, are all relevant and must be incorporated. What is shown on the map should convey a picture not only of the soil profiles but also whatever information on these outlines as can be readily incorporated in the mapping scheme. Considerable detailed work along these lines has already been done not only in U.S.A. but also in East Africa (vide G. Milne's "Some Aspects of Modern Practice in Soil Survey", *East African Agricultural Journal,* 1940).

13. 27. *Use of air-photos.*—A "mosaic" is a series of photographs taken vertically from an aeroplane so that a continuous series of photos covers the entire ground with some overlapping. The mosaic is prepared by trimming each print to eliminate this overlap so that the whole can be affixed to a mounting board to give a composite photograph of the entire area.

PLATE

Airphoto of badly ravined land. Identical area as is shown in Figure 47. Note enhanced detail.

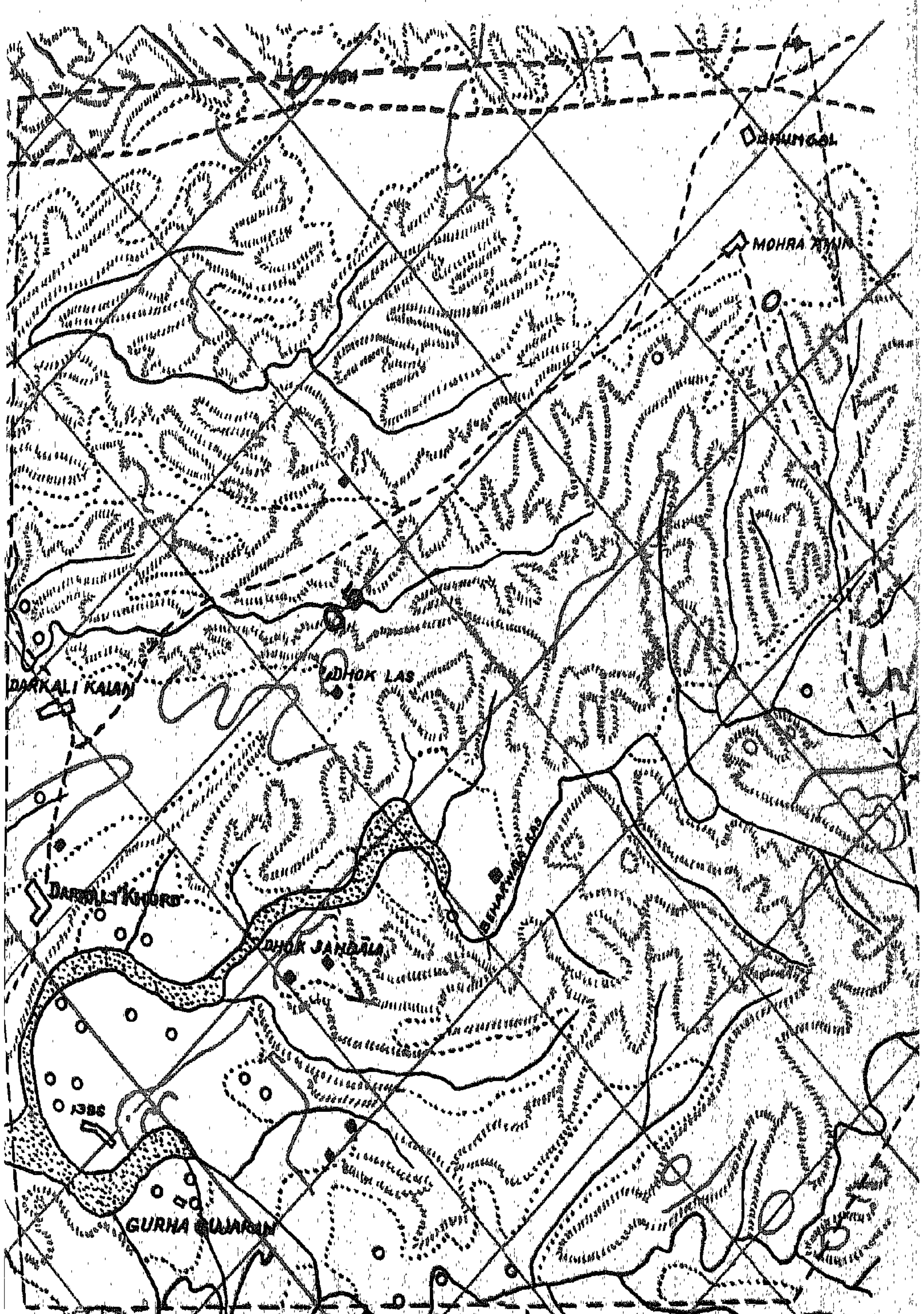


FIGURE 47.
COMPARISON OF SURVEY SHEET AND AIR-PHOTO
RAWALPINDI DISTT. (SHEET No. 43G/3 & G/4
SCALE 2 INCHES=1 MILE.

The advantages of air photos and particularly of mosaics prepared in this way over ordinary survey maps are as follows:—

a. they give a more exact and detailed image of individual features, (compare Plate 27 and Figure 47).

b. photos of particular features can be enlarged several times to give further detail.

c. examined by stereoscope they show relief very clearly.

d. they bring out certain facts not apparent to observers on the ground.

e. close study of erosion intensity and extent can be made in the office.

f. an air mosaic once taken forms permanent evidence of the condition of the area on that date so that subsequent deterioration or improvement can be accurately known. This is particularly valuable in torrent reclamation.

g. the siting of bunds, the selection of nala heads for gully plugging, and the planning of other soil conservation work is facilitated.

(R. Kemp's cyclostyled *Air Survey and Soil Erosion*, I.A.S. & T. Coy., Dumdum, Calcutta, and *Indian Forester*, Septr. 1946).

13. 28. *Road Drainage.*—The building of a road upsets the natural drainage of the area it passes through and tends to concentrate run-off into culverts. If the road blocks certain natural drainage channels and forces the run-off from several of these into one culvert, the concentrated outflow from this culvert puts a severe strain on the channel. If this channel is erodible it tends to cut deeply, and subsequently this gully works back uphill and may quite easily destroy the road itself. The cure for this is (a) to provide a culvert for each natural drainage channel, (b) to ensure harmless discharge by stepping down the bed with masonry sills to a safe distance below the road, (c) to provide a still-water basin at the outlet end of large culverts thus preventing the water from destructive cutting.

13. 29. In building and maintaining earth roads, long stretches of the same slope must be broken up by making cross-drains or cross *watts* shaped so that they interfere as little as possible with wheeled traffic, but designed to remove the surface water into a side drain. Side-drains in both earth and macadam roadways are also apt to cut deeply if the subsoil is erodible. In such land side-drains must be stepped throughout their length with masonry or brick sills. In view of constant roadside grazing it is not advisable to depend upon vegetation

to preserve the shape and slope of roadside drainage channels. In view of the complications arising from the bad alignment or roads or lack of attention to road drainage disposal, it may be advisable to consult a road engineer in addition to the other specialists involved, but it should not as a rule be necessary to have a roads officer detailed to accompany the working plan or survey party throughout.

13. 30. *Provincial Land Utilization Board.*—It is obvious from the foregoing chapters that much of this programme of soil and water conservation is beyond the strict limits of forestry and requires a knowledge of many other sciences. Similarly in the field of administration many problems arise which should actually be handled by one or other of the departments concerned. To quote from the Annual Report of the Department of Conservation of New South Wales, 1945:—"So great is the importance of the matter that the Commission suggests that each State Government should set up a Land Utilisation authority as a special organisation under the control of the Premier. This organisation should preferably take the form of a standing council. consisting of the heads of departments of Agriculture, Forests, Lands and Survey and Water Supply. In States where Soil Conservation is not under the administration of one of these departments, the head of the Soil Conservation Authority should also be a member. This central Land Utilisation Council would have the task of co-ordinating the State policy on all matters of alienation, forest developments, water resources (in so far as they are affected by method of land use) and erosion control." Quotations could also be given from several other countries in which similar decisions have been reached.

13. 31. As long as Soil Conservation in the Punjab is entrusted to a circle under the Chief Conservator of Forests the difficulty of handling non-forest problems will remain, and can best be met by recruiting on loan whatever other officers are required from their respective departments. If this were done it would also overcome the difficulty described above of framing comprehensive land management proposals for each catchment area, as our catchment working plan officers would then have the benefit of advice from these specialists part of whose job would be to constitute a team dealing with non-forest problems which arise in the preparation of each catchment plan. They would also be available for similar team work to help with the planning and choice of areas for mechanised reclamation.

13. 32. The Forest Department's 5-year plan (Appendix I) involves the co-operation of several departments; these de-

partments all have their own plans, but none of them directly requires the assistance of the Forest Department; all of them will be busy with their own work. If, therefore, the numerous problems which will arise are left to be settled through the usual departmental machinery, there will be endless delays and the more urgent parts of the plan (such as those covered with the employment and resettlement of ex-soldiers) will certainly fail. The land surveys will take a long time and they will raise numerous issues on which it is unnecessary to dilate here. Progress will be slow unless the whole matter is tackled on broad lines, and for this purpose the setting up of a Land Utilization Board, with *ad hoc* powers, seems essential. Some of the functions of this Board, would be:—

(a) to control and co-ordinate local land utilization surveys.

(b) to make decisions on problems arising out of the surveys and to allocate the land to its best use.

(c) to decide policy under which cultivated land should be given up as such and put under a protective regime e.g., where land is being lost by river action, or erosion is being caused by cultivation on steep slopes.

(d) to deal with questions relating to the acquisition of privately owned waste for afforestation.

(e) to provide for the proper functioning of regional soil conservation plans which involves the participation of several departments.

(f) to scrutinise plans submitted by the Forest Department for the conservation of vital catchment areas.

(g) to so direct large-scale land-planning operations that unavoidable changes in rural economy, even though they may ultimately benefit those concerned, cause as little hardship as possible during the transition; such would be the case when a tract which has been under a regime mainly pastoral, is to be developed through a combination of improved agriculture and afforestation e.g., the huge Thal tract in the Western Punjab.

This committee might be composed of 1 officer each of the following departments:—Revenue, Agriculture, Co-operative, Forests, and an officer of the Irrigation Branch. It would be a standing committee and would have to be vested with powers to make decisions in accordance with the policy prescribed by Government.

13. 33. *Forestry and Food Production.*—This book has attempted to show that foresters can take a hand in the essential task of producing more food for the nation by making every acre of wild land more productive. Their previous role as custodians of existing government forests, whose boundaries were at best rather haphazard, is gradually altering as the wider implications of soil and water conservation become known. This change is demonstrated by such happenings as the Food and Agriculture Organisation of the United Nations having included forestry as one of their essential activities in Washington, while in the British Empire the string of twelve Imperial Agricultural Bureax, of which forestry is one, has come under the control of an ex-Inspector-General of Forests for India. But the forester can function as a producer of food only insofar as the other land managing departments of government and the non-government land-holding agencies combine as a team to implement a well thought-out land use programme which aims at making every acre more productive. And that in the Punjab is synonymous with catching every drop of rain where it falls.

APPENDIX I—EXTRACT FROM "POST-WAR DEVELOPMENT PLAN, PUNJAB"; (SUPERINTENDENT GOVERNMENT PRINTING PUNJAB, 1945).

Chapter IV. Afforestation and Anti-erosion Measures.

2. The first item in the Forest Department's proposals is the reclamation of eroding cultivation and of ravined lands. Very large blocks of so-called *darrar* lands badly cut up by deep ravines have rendered cultivation impossible and the individual cultivator single-handed has often abandoned the struggle to save his land from the ever spreading gully. A few instances of reclamation work carried out by the Co-operative Societies under the guidance of the Forest Department have shown that with proper guidance and co-ordination the community can save its own land. With the aid of earth-moving machinery such as the Army is now familiar with such work becomes correspondingly easier and quicker. Heavy earth-moving equipment consisting of bull-dozers, terracers, sub-soilers and other specialised equipment will be required and must be purchased abroad unless the Army can make suitable surplus war material machines available as early as possible after the Japanese War is finished. The scheme is expected to reclaim 150,000 acres of now useless *darrar*, and to increase the productivity of 350,000 acres of poor and unterraced land already threatened with erosion. The areas in which large blocks of *darrar* land occur are incidentally those which have done best in recruitment, namely Rawalpindi, Jhelum, Attock, Gujrat, Hoshiarpur and Ambala, so that whatever reclamation is effected will be a direct contribution towards resettlement of the soldiers.

3. The next item in the Forest Department's programme is the reclamation and improvement of waste land to make them more productive in terms of timber, firewood, fodder grass, thatching grass, resin and gum extraction and the many other similar items of minor forest produce which can add to the villagers' income. In order to do this, however, the one essential factor is the control of grazing. At present practically all the village waste land in the province is deteriorating and lapsing into treeless and unproductive desert owing to the incessant and persistent damage caused by uncontrolled grazing. Along the bed of every torrent, small stream and large river in the province there are vast areas of land now quite unproductive. Given protection from grazing and an energetic planting programme such

as has already been adopted by several hundreds of co-operative societies these river beds can to a great extent be made productive. Particularly below the Hoshiarpur and Ambala Siwaliks these torrent beds are capable of producing several million tons of sissoo which is probably the best wood in the world for general construction, furniture and agricultural purposes.

4. The third part of this afforestation programme is the scientific management of all the avenue trees in the province whether they belong to the Irrigation Branch, District Boards or the Public Works Department, Buildings and Roads. The recent so-called firewood famine need not have been so severely felt if these various departments and public bodies who own avenues had taken timely steps to make available to the towns many dead and dying trees in their avenues. Our object now should be to ensure that all waste land on the edges of roads, canals and railways is fully stocked with young trees, the watering and protection of which over many miles of land which is difficult to protect will require a considerable staff, but the return which the Punjab will secure cannot be expressed in terms of rupees alone, because benefits of a sound arboriculture include not only cash returns but also improved amenities of shade, shelter and beauty.

5. The conservation of the vital water catchment areas of the Punjab rivers holds great importance for the Irrigation Engineers and for many years the Central Board of Irrigation has been clamouring for more effective conservation measures in the high hill catchments which serve the major canals. Now in addition we have an ambitious programme of high dams. Each of these dams will block the passage of a river whose load of silt and sand has previously been carried out either to the sea or spread afar by the irrigation water. With the complete stoppage of the stream-flow, its entire load of silt, sand, pebbles and boulders will be dumped on the bottom in the reservoir behind the dam.

6. The load of silt and sand carried by the Beas and the Sutlej is particularly bad in times of heavy flood when the snow melting in the high hills combines with torrential down-pours and heavy erosion damage in the foothills. The Bhakra dam on the Sutlej and Sirmur dam on the Giri are already in hand and plans for others on the Beas and Ravi are being prepared. Every effort must, therefore, be made to ensure that catchment areas above dam sites are in the best possible condition to reduce siltation. This entails much stricter control of grazing than has ever before been attempted, and cancellation or commutation of grazing rights which are found to be harmful. In the case of Kangra particularly it needs a radical reduction in the number

of grazing animals. It has recently been computed that Kangra now holds 1,000,000 livestock although it is capable of feeding only 200,000 properly with the existing facilities for grazing grass cutting.

7. Next we have the reclamation of thur land and waterlogged areas. Neither of these are strictly speaking forestry problems, but much of the land which has gone out of cultivation owing to its heavy salt content or owing to waterlogging is in such a bad condition that it is unlikely ever to be rendered fit for cultivation and can at best be expected to produce a tree crop. Trees in many cases will be a means to an end because their very presence assists to re-establish a productive soil and a better drainage. Where irrigation water is available thur salt can be cancelled by growing two or three crops of rice, then putting it under trees for a number of years. Similarly in waterlogged land when drains are first opened a tree crop may give a better return than any field crop would in the first few years during which drainage is being introduced.

8. The last but by no means the least important of the forest department's proposed activities is in esablishing wind-breaks and shelter-belts to control the movement of wind-blown sand. Everyone must be familiar with the tragic tale of the American "Dust Bowl" where ill-considered ploughing of natural grasslands and failure to provide shelter-belts in a hot and wind-swept country somewhat similar to our southern Punjab with extremes of poverty and suffering which have been ameliorated to some extent by Federal Government action in planting a vast number of narrow shelter-belts along field borders, roads, railways and waste lands to form a defence against the prevailing wind. Unless some similar project is worked out for our desert fringe districts of Gurgaon, Hissar, Sirsa, Ferozepore, Fazilka, Multan and the vast tract of the Thal desert between the Indus and the Jhelum, increasing poverty and aridity in this already treeless tract is unavoidable. Just how far such a programme can actually make land available for ex-servicemen is not yet clear, but the first step is to demonstrate to the residents of these areas the value of shelter-belts of trees and in areas where trees cannot be grown, wind-breaks of kana grass can be used to stop the shifting sand.

The Forest Department proposes to carry out contour bunding work in all the Punjab desert-fringe districts with the co-operation of the agriculture department in working out details of land use and crop production in the reclaimed areas.

9. The 5 years' programme outlines the employment of very large numbers of men for labour, and the expansion of our techni-

cally trained staff. These developments have already been anticipated to some extent and the training colleges for Officers and Rangers at Dehra Dun and Foresters at Ghora Gali are being expanded. It is hoped that many of those who would be selected for training will be ex-servicemen but apart from these higher grades of technically trained officials there will also be a big demand for ex-soldiers in posts of daroghas, forest guards and co-operative society guards.

10. The approximate cost of the schemes is given below—

IN THOUSANDS OF RUPEES.

Scheme No.	Scheme.	Category of Scheme	APPROXIMATE COST OF THE FIVE-YEAR PLAN			Annual recurring expenditure at the end of five years
			Capital.	Recurring.	Total.	
16	Purchase of machinery for training and experimental purposes.	Special priority.	2,00	...	2,00	...
17	Cadre expansion ...	All-Province	9,00	19,00	28,00	7,00
18	Planting of canal and roadside avenue trees.	Ditto	16,00	...	16,00	...
19	Soil Conservation ... (including 8 lakhs machinery).	Particular area.	1,54,00	...	1,54,00	...
	Total	...	1,81,00	19,00	2,00,00	7,00

APPENDIX II—PUNJAB LAND PRESERVATION (CHOS) ACT, 1900 (PUNJAB ACT II OF 1900).

As Modified up to 1st July 1944

An Act to provide for the better preservation and protection of certain portions of the territories of the Punjab.

* * * * * *[1]

* * * * * *[2]

It is hereby enacted as follows:—

Preliminary.

Short title and commencement.

1. (1) This Act may be called the Punjab Land Preservation *[3]* Act, 1900.

[4]((2) Sections 8, 9 and 10 shall extend to the territories situate within and adjacent to the Siwalik mountain range; the remaining sections shall extend to the whole of the Punjab.)

(3) It shall come into force at once.

Definitions.

2. In this Act unless a different intention appears from the subject or context—

(a) the expression "land" means land within any *[5]* area preserved and protected or otherwise dealt with in manner in this Act provided, and includes benefits to arise out of land, and things attached to the earth or permanently fastened to anything attached to the earth;

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1 The words "situate within or adacent to the Siwalik mountain range" omitted by Punjab Act XI of 1942, section 2.

2 The preamble omitted by Punjab Act XI of 1942, section 3.

3 The brackets and word '(Chos)' was omitted by Punjab Act IV of 1944, section 2.

4 Sub-section (2) was inserted by Punjab Act XI of 1942, section 4, which again was substituted by Punjab Act IV of 1944, section 2.

5 The word "Local" omitted by Punjab Act IV of 1944, section 3.

(b) the expression "cho" means a stream or torrent flowing through or from the Siwalik mountain range within the Punjab;

(c) the expression "tree," "timber", "forest produce" and "cattle", respectively, shall have the meanings severally assigned thereto in section 2 of the Indian Forest Act (1927)[1]; XVI of 1927

(d) the expression "person interested" includes all persons claiming any interest in compensation to be made on account of any measures taken under this Act; *[2]*

(e) the expression "Deputy Commissioner" includes any officer or officers at any time specially appointed by the [3](Provincial Government) to perform the functions of a Deputy Commissioner under this Act;

(f) the expression "rightholder" includes—

(i) persons not being tenants or mortgagees having rights to or in land; and

(ii) persons having rights of collection of forest produce or of grazing or pasture; and

(g) the expression "erosion" includes the removal or displacement of earth, soil, stones or other materials by the action of wind or water.[4]

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1 Substituted for the figures "1878" by Punjab Act IV of 1944, section 3.

2 The word "and" omitted by Punjab Act IV of 1944, section 3.

3 Substituted for the words "Local Government" by the Government of India (Adaptation of Indian Laws) Order, 1937.

4 Clauses (*f*) and (*g*) added by Punjab Act IV of 1944, section 3.

NOTIFICATION AND REGULATION OF AREAS.

Notification of areas.

[1](3. Whenever it appears to the Provincial Government that it is desirable to provide for the conservation of sub-soil water or the prevention of erosion in any area subject to erosion or likely to become liable to erosion, such Government may by notification[2] make a direction accordingly.)

Power to regulate, restrict or prohibit, by general or special order, within notified areas, certain matters.

4. In respect of areas notified under section 3 generally or the whole or any part of any such area, the [3](Provincial Government) may, by general or special order, temporarily [4]***** regulate, restrict or prohibit—

(a) the clearing or breaking up or cultivating of land not ordinarily under cultivation prior to the publication of the notification under section 3;

(b) the quarrying of stone or the burning of lime at places where such stone or lime had not ordinarily been so quarried or burnt prior to the publication of the notification under section 3;

(c) the cutting of trees or timber, or the collection or removal or subjection to any manufacturing process, otherwise than as described in clause (b) of this sub-section of any forest-produce other than grass, save for *bona fide* domestic or agricultural purposes [5](of right-holder in such area);

(d) the setting on fire of trees, timber or forest produce;

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1 Section 3 substituted by Punjab Act XI of 1942, section 5.

2 For notification *see* Punjab Local Rules and Orders.

3 Substituted for the words "Local Government" by the Government of India (Adaptation of Indian Laws) Order, 1937.

4 The words "or permanently" were omitted by Punjab Act VII of 1923, section 2.

5 Inserted by Punjab Act IV of 1944, section 4.

(e) the admission, herding, pasturing or retention of sheep [1](goats or camels);

(f) the examination of forest-produce passing out of any such area; and

(g) the granting of permits to the inhabitants of towns and villages situate within the limits or in the vicinity of any such area, to take any tree, timber or forest produce for their own use therefrom, or to pasture sheep [1](goats or camels), or to cultivate or erect buildings therein and the production and return of such permits by such persons.

Power, in certain cases, to regulate, restrict or prohibit, by special order, within notified areas, certain further matters

[2]5. In respect of any specified village or villages, or part or parts thereof, comprised within the limits of any area notified under section 3 the [3](Provincial Government) may, by special order, temporarily*[4]* regulate restrict or prohibit—

(a) the cultivating of any land ordinarily under cultivation prior to the publication of the notification under section 3;

(b) the quarrying of any stone or the burning of any lime at places where such stone or line has ordinarily been so quarried or burnt prior to the publication of the notification under section 3;

(c) the cutting of trees and timber or the collection or removal or subjection to any manufacturing process, otherwise than as described in clause (b) of this sub-section of any forest-produce [5](for any purposes); and

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[1] Inserted by Punjab Act IV of 1944, section 4.

[2] For notification *see* Punjab Local Rules and Orders.

[3] Substituted for the words "Local Government" by Government of India (Adaptation of Indian Laws) Order, 1937.

[4] The words "or permanently" were omitted by Punjab Act, VII of 1926, section 3.

[5] Substituted for the words "for *bona fide* domestic or agricultural purposes" by Punjab Act IV of 1905.

(d) the admission, herding, pasturing or retention of cattle generally other than sheep [1](goats and camels), or of any class or description of such cattle.

Power to require execution of works and taking of measures.

[2](5-A. In respect of areas notified under section 3 generally or the whole or any part of any such area, the Provincial Government may, by general or special order, direct—

(a) the levelling, terracing, drainage and embanking of fields;

(b) the construction of earth-works in fields and ravines;

(c) the provision of drains for storm water;

(d) the protection of land against the action of wind or water;

(e) the training of streams; and

(f) the execution of such other works and the carrying out of such other measures as may in the opinion of the Provincial Government, be necessary for carrying out the purposes of this Act.)

Necessity for regulation, restriction or prohibition to be recited in the order under section 4 or 5.

6. Every order made under [3](sections 4, 5, or 5-A) shall be published in the [4]Official Gazette and shall set forth that the [5](Provincial Government) is satisfied, after due

1 Substituted for the words "and goats" by Punjab Act IV of 1944, section 5.

2 Section 5-A added by Punjab Act IV of 1944, section 6.

3 Substituted for the words and figures "section 4 or section 5" by Punjab Act IV of 1944, section 7.

4 Substituted for the word "Gazette" by Government of India (Adaptation of Indian Laws) Order, 1937.

5 Substituted for the words "Local Government" by Government of India (Adaptation of Indian Laws) Order, 1937.

inquiry, that regulations, restrictions [1](prohibitions or directions), contained in the order are necessary for the purpose of giving effect to the provisions of this Act.

Proclamation of regulations, restrictions and prohibitions and admission of claims for compensation for rights which are restricted or extinguished.

7. (1) When, in respect of any *[2]*area, a notification has been published under section 3, and—

(a) upon such publication any general order, made under section 4 [3](or section 5-A) becomes applicable to such area; or

(b) any special order under [4](sections 4, 5 or 5-A), is made in respect of such area;

the Deputy Commissioner shall cause public notice of the provisions of such general or special order to be given, and if the provisions of any such order restrict or [5](prohibit the exercise of) any existing rights, shall also publish in the language of the country and in every town and village the boundaries of which include any portion of the area within or over which the [6](exercise of any such rights is so restricted or prohibited) a proclamation stating the regulations, restrictions and prohibitions which have been imposed, by any such order, within the limits of such area or in any part or parts thereof fixing a period of not less than three months from the date of such proclamation, and requiring every person claiming any compensation in respect of any right so restricted or prohibited, within

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1 Substituted for the words "or prohibitions" by Punjab Act IV of 1944, section 7.

2 The word "local" omitted by Punjab Act IV of 1944, section 8.

3 Inserted by Punjab Act IV of 1944, section 8.

4 Substituted for the words and figures "section 4 or section 5" by Punjab Act IV of 1944, section 8.

5 Substituted for the word "extinguish" by Punjab Act VII of 1926, section 4.

6 Substituted for the words "any such rights are so restricted or extinguished" by Punjab Act VII of 1926, section 4.

such period either to present to such officer a written notice specifying, or to appear before him and state, the nature and extent of such right and the amount and particulars of the compensation (if any) claimed in respect thereof.

(2) Any claim not preferred within the time fixed in the proclamation made under sub-section (1), shall be rejected;

Provided that, with the previous sanction of the Commissioner, the Deputy Commissioner may admit any such claim as if it had been made within such period.

[1](7-A. (1) When an order has issued under section 5-A, the Deputy Commissioner may by notice require the owner or occupier of the land to execute such works or take such measures as may be specified in the notice. Enforcement of orders made under section 5-A.

(2) Every such notice shall state the time within which the works are to be executed or measures are to be taken.

(3) A person aggrieved by an order contained in such a notice as aforesaid may, within thirty days from the service of such notice or within such longer period as the Deputy Commissioner may allow in this behalf, serve a notice of his objections on the Deputy Commissioner in such manner as may be provided by the rules made under this Act.

(4) if and in so far as an objection under this section is based on the ground of some informality, defect or error in or in connection with the notice, the Deputy Commissioner shall dismiss the objection, if he is satisfied that the informality, defect or error was not a material one.

(5) If the objection is brought on all or any of the following grounds, that is to say:—

(a) that the notice might lawfully have been served on the occupier of the land in question instead of on the

1 Section 7-A added by Punjab Act IV of 1944, section 9.

owner, or on the owner instead of on the occupier, and that it would have been equitable for it to have been so served;

(b) that some other person, being the owner, occupancy tenant, mortgagee with possession or lessee or farm-holder or possessing some other right in or over the land to be benefited, ought to contribute towards the expense of executing any works or taking any measures required;

(c) where the work or measure is work or measure for the common benefit of the land in question and other land, that some other person, being the owner or occupier of land to be benefited, ought to contribute towards the expenses of executing any works or taking any measures required;

the objector shall serve a copy of his notice of objection on each other person referred to, and on the hearing of the objection the Deputy Commissioner may make such order as he thinks fit with respect to the person by whom any work is to be executed or measure is to be taken and the contribution to be made by any other person towards the cost of the work or measure or as to the proportions in which any expenses which may become recoverable by the Deputy Commissioner under sub-section (6) are to be borne by the objector and such other person;

Provided that no such order shall be made unless the person who is likely to be affected thereby has been given a reasonable opportunity of being heard.

In exercising his power under this sub-section the Deputy Commissioner shall have regard—

(a) as between an owner and an occupier, to the terms and conditions, whether contractual or statutory, of

the tenancy and to the nature of works and measures required; and

(b) in any case, to the degree of benefit to be derived by the different persons concerned.

(6) Notwithstanding anything to the contrary in any law for the time being in force, no person required by a notice or an order under this section to execute any work or to take any measure shall be required to obtain the consent of any other person before complying with such notice or order.

(7) Subject to such right of objection as aforesaid and the right of appeal under section 18, if the person required by the notice to execute works or to take measures fails to execute, the works or to take the measures indicated within the time thereby limited, the Deputy Commissioner may himself or by an agent execute the works or take the measures and recover from that person the expenses reasonably incurred by him in so doing;

(a) provided that it shall not be necessary for the Deputy Commissioner to wait for the decision of any objection other than an objection under clause (a) of sub-section (5), or an appeal against any decision on such objection, before taking action under this sub-section;

(b) provided further that the maximum amount that shall be recoverable in respect of any land in regard to which the work has been executed or the measure taken shall not exceed--

(i) where the work is required to be executed or the measure to be taken by the owner, ten times the land revenue assessed on all the lands owned by him in the Punjab; and

(ii) where the work is required to be executed by the occupier, ten times the land revenue assessed on all the

lands occupied by him in the estate in which such land is situated.

(8) If the cost of any work executed or any measure taken by any person remains unpaid by the person from whom it is due after the date specified in a notice issued in this behalf by the Deputy Commissioner or such other date as is fixed by him, such cost shall be recoverable as an arrear of land revenue and a certificate issued by the Deputy Commissioner in this behalf shall be final and conclusive evidence of the sum so recoverable and the person liable for the same.

(9) Every order issued under this section shall be published in such manner as may be prescribed in the rules made under this Act. and upon such publication every person affected thereby shall, unless the contrary be proved, be deemed to have had due notice thereof.

(10) The Deputy Commissioner may by general or special order authorise any revenue officer subordinate to him to enquire into any objection that may be brought under this section;

Provided that no final order on any such objection shall be passed except by the Deputy Commissioner himself.

(11) In making an order on objections brought under this section, the Deputy Commissioner shall be guided by such rules, if any, as the Provincial Government make in this behalf.

(12) For the purposes of this section, the expression "estate" shall have the meaning assigned thereto in the Punjab Land Revenue Act, 1887.)

CONTROL OVER THE BEDS OF CHOS.

8. (1) Whenever it appears to the [1](Provincial Government) that it is desirable that measures should be taken in the bed of any cho for the purpose of—

Action when Provincial Government considers it desirable to take measures to regulate the beds of chos. Vesting of such beds in His Majesty.

(a) regulating the flow of water within and preventing the widening or extension of such bed; or of

(b) reclaiming or protecting any land situate within the limits of such bed;

such Government, may, either proceed at once in manner in sub-section (2) provided, or, in the first instance, by notification specifying the nature and extent of the measures to be taken and the locality in and the time within which such measures are to be so taken, require all persons possessing proprietary or occupancy right in land situate in such locality to themselves carry out the measures specified in such notification accordingly.

(2) If the whole or any part of the bed of any cho unclaimed, or if, in the opinion of the [1](Provincial Government) the measures deemed necessary under sub-section (1) are of such a character, in regard to extent and cost, that the interference of the [1](Provincial Government) is absolutely necessary, or in the event of the owner or occupier of any portion of the bed of any cho failing to comply with the requirements of any notification issued under sub-section (1), such Government may, by notification, declare that the whole or any part of the area comprised within the limits of the bed of any cho shall [2](Vest in His Majesty for the purposes of the Province) ***[3] for such period and subject to such conditions (if any) as may be specified in the notification.

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[1] Substituted for the words "Local Government" by the Government of India (Adaptation of Indian Laws) Order, 1937.

[2] Substituted for words "Vest in the Government" by the Government of India (Adaptation of Indian Laws) Orders, 1937.

[3] The words "either absolutely and in perpetuity or were" omitted by Punjab Act, VIII of 1926, Section 2.

Provided that no such declaration shall be made in respect of or shall affect any land included within the limits of the bed of any such cho, which, at the date of the publication of the notification making such declaration, is cultivated or culturable, or yields any produce of substantial value.

(3) When the owners or occupiers of such locality are unable to agree among themselves regarding the carrying out of such measures, the decision of those paying the larger amount of land revenue shall be held to be binding on all.

(4) The [1](Provincial Government) may, from time to time, by like notification, extend the period during which any such area shall remain vested in [2](His Majesty).

Effect of notification to suspend or extinguish private rights in the area notified under section 8.

9. Upon the making of any declaration under sub-section (2) of section 8, all private rights of whatever kind existing in or relating to any land comprised within the area specified in the notification containing such declaration at the time of the publication thereof, [3](shall be suspended for the period specified in the declaration and for such further period (if any) to which such period may at any time be extended).

Provided that, as far as circumstances admit, such rights of way and water shall be reserved, in respect of every such area, as may be necessary to meet the reasonable requirements and convenience of the persons (if any) who, at the time of the making of such declaration, possessed any such rights over such area.

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1 Substituted for the words "Local Government" by the Government of India (Adaptation of Indian Laws) Order, 1937.

2 Substituted for the words "the Government" by the Government of India (Adaptation of Indian Laws) Order, 1937.

3 Substituted by Punjab Act, VIII of 1926, section 3 for the following clauses:—

(a) if no period is specified in such declaration—cease and determine absolutely.

(b) if any period is specified in such declaration—be suspended for such period and for such further period (if any) to which such period may at any time be extended.

10. (1) The Deputy Commissioner shall, for the purposes of every notification issued under sub-section (2) of section 8, fix the limits of the area comprised within the bed of the cho to which such notification is to apply.

Power of Deputy Commissioner to delimit the bed and to decide what constitutes such bed.

(2) Upon the publication of a notification containing any declaration under sub-section (2) of section 8, it shall be lawful for the Deputy Commissioner, to—

Power to take possession of bed when vested in His Majesty.

(a) take possession of the area specified in such declaration;

(b) eject all persons therefrom; and to

(c) deal with such area, while it remains vested in [1](His Majesty) as if it were the absolute property of [1](His Majesty).

Bar of compensation for acts done under sections 8, 9 or 10.

11. No person shall be entitled to any compensation for anything at any time done, in good faith in exercise of any power conferred by section 8, section 9 or section 10.

12. *(Condition as to sale of land acquired under the Act and obligation of Local Government to keep account of money expended on such land) Repealed by Act VIII of 1926, section 4.*

POWER TO ENTER UPON AND DELIMIT NOTIFIED AREAS AND BEDS.

13. It shall be lawful for the Deputy Commissioner and for his subordinate officers, servants, caretakers and workmen, from time to time, as occasion may require—

Power to enter upon survey and demarcate local areas notified under section 3 or section 8

(a) to enter upon and survey any land comprised within any **[2] area in regard to which any notification has been issued under section 3 or sec-

1 Substituted for the words "the Government" by the Government of India (Adaptation of Indian Laws) Order, 1937.

2 The word "local" was omitted by Punjab Act IV of 1944, section 10.

tion 8 [1](or in regard to which a notification is proposed to be issued under section 5-A);

(b) to erect bench-marks on and to delimit and demarcate the boundaries of any such **[2] area; and

(c) to do all other acts and things which may be necessary in order adequately to preserve or protect any land or to give effect to all or any of the provisions of this Act;

Provided that reasonable compensation, to be assessed and determined in the manner in this Act provided, shall be made in respect of any damage or injury caused to the property or rights of any person in carrying out any operations under the provisions of this section, but no such compensation shall be payable in respect of any thing done under the said provisions within the limits of any [3]**area notified under section 8.

INQUIRY INTO CLAIMS AND AWARD OF COMPENSATION.

Inquiries in to claims and awards thereupon.

14. (1) The Deputy Commissioner shall—

(a) fix a date for inquiring into all claims made under section 7 *[4]* and may in his discretion from time to time adjourn the inquiry to a date to be fixed by him;

(b) record in writing all statements made under section 7;

(c) inquire into all claims duly preferred under section 7 *[4]*; and

(d) make an award upon each such claim, setting out therein the nature and extent of the right claimed, the person or persons making such claim,

[1] The word "local" was omitted by Punjab Act IV of 1944, section 10.

[2] Added by Punjab Act IV of 1944, section 10.

[3] The words and figures "or section 12" were omitted by the Punjab Act VIII of 1926, section 5.

[4] The words "or section 12" were omitted by Punjab Act, VIII of 1926, section 5.

the extent (if any) to which, and the person, or persons in whose favour, the right claimed is established, the extent to which it is to be restricted [1](or prohibited and the nature and amount of the compensation (if any) awarded.)

(2) For the purposes of every such inquiry the Deputy Commissioner may exercise all or any of the powers of a Civil Court in the trial of suits under the [2]Code of Civil Procedure.

(3) The Deputy Commissioner shall announce his award to such persons interested, or their representatives, as are present, and shall record the acceptance of those who accept it. To such as are not present, the Deputy Commissioner shall cause immediate notice of his award to be given. Act XIV of 1882

Method of awarding compensation and effect of such award.

15. (1) In determining the amount of compensation, the Deputy Commissioner shall be guided, so far as may be, by the provisions of sections 23 and 24 of the [3]Land Acquisition Act, 1894, and as to matters which cannot be dealt with under those provisions, by what is just and reasonable in the circumstances of each case. Act I of 1894

(2) The Deputy Commissioner may, with the sanction of the [4](Provincial Government) and the consent of the person entitled, instead of money award compensation in land or by reduction in revenue or in any other form.

(3) If in any case, the exercise of any right is prohibited for a time only, compensation shall be awarded only in respect of the period

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1 Substituted for the word "extinguished" by Punjab Act, VIII of 1926, section 5.

2 See now the Code of Civil Procedure, 1908 (Act V of 1908), Unrepealed Central Acts, Volume V.

3 See Unrepealed Central Acts, Volume III.

4 Substituted for the words "Local Government" by the Government of India (Adaptation of Indian Laws) Order, 1937.

during which the exercise of such right is so prohibited.

[1](4) * * *

PROCEDURE, RECORDS AND APPEAL

Record of rights in respect of notified area.

16. (1) For every area, notified under section 3 or section 8, the Deputy Commissioner shall prepare a record setting forth the nature, description, local situation and extent of all rights mentioned in section 4 and section 5.

(a) existing within such area at the time of the publication of the notification relating thereto under section 3 or section 8;

(b) regulated, restricted or * [2] * [3](prohibited) by any order under section 4 or section 5.

(2) When any award is made under section 14, its effect upon any right shall also be recorded therein.

Mode of proclaiming notifications and of serving notices, order and processes issued under the A ct.

17. (1) Upon the publication of a notification issued under any of the provisions of this Act, the Deputy Commissioner shall cause public notice of the substance thereof to be given at convenient places in the locality to which such notification relates.

(2) The procedure prescribed in sections 20, 21 and 22 of the [4]Punjab Land Revenue Act, 1887, shall be followed, as far as may be, in proceedings under this Act. XVII 1887.

Appeal, review and revision.

18. Every order passed and every award made by a Deputy Commissioner under this Act, shall, for the purposes of appeal, review and revision, respectively be deemed to be the order of a Collector within the meaning

1 Repealed by the Punjab Act VIII of 1926, section 6.

2 The word "suspended" was omitted by Punjab Act, VIII of 1926, section 7.

3 Substituted for the word "extinguished" by Punjab Act, VIII of 1926, section 7.

4 See Volume I of Punjab Code.

of sections 13, 14, 15 and 16 of the [1]Punjab Land Revenue Act, 1887. XVII of 1887.

Provided that nothing in this Act contained shall be deemed to exclude the jurisdiction of any Civil Court to decide any dispute arising between the person interested in any compensation awarded as to the apportionment or distribution thereof amongst such persons or any of them.

PENALTIES, BAR OF SUITS AND RULES.

Penalty for offences.

19. Any person who, within the limits of any,[2]*** area notified under section 3, commits any breach of any regulation made. [3](restriction or prohibition imposed, order passed or requisition made under sections 4, 5, 5-A, or 7-A), shall be punished with imprisonment for a term which may extend to one month, for with a fine which may extend to one hundred rupees, or with both.

Application of provisions of Act XVI of 1927.

20. [4](The provisions of sections 52, 54, 55, 56, 57, 58, 59, 60, 61, 62 and 64 (excluding the last sentence), 66, 67, 68 and 73 of the Indian Forest Act, 1927), shall so far as applicable, be read as part of this Act, and for the purposes of those provisions, every offence punishable under section 19 shall be deemed to be a "forest offence", and every officer employed in the management of any area notified under section 3 or section 8, as care-taker or otherwise, shall be deemed to be a forest officer. XVI of 1927

1 See Volume I of Punjab Code.

2 The word "local" was omitted by Punjab Act IV of 1944, section 11.

3 Substituted for the words "or restriction or prohibition imposed under section 4 or section 5" by Punjab Act IV of 1944, section 11.

4 Substituted for the words, figures and brackets "The provisions of sections 52, 53, 54, 55, 56, 57 58, 59, 60, 61 and 63 (excluding the last sentence), 64, 65, 66, 67 and 72 of Indian Forest Act 1878" by Punjab Act V of 1944, section 12.

Bar of suits.

21. No suit shall lie against [1](the Crown) for anything done under this Act, and no suit shall lie against any public servant for anything done, or purporting to have been done, by him, in good faith, under this Act.

Power to make rules.

22. (1) The [2](Provincial Government) may make rules, consistent with this Act—

(a) regulating the procedure to be observed in any inquiry or proceeding under this Act; and

(b) generally for the purpose of carrying into effect all or any of the provisions of this Act.

(2) All rules made under this section shall be published in the [3](Official Gazette).

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1 Substituted for the words "the Secretary of State for India in Council, or the Government by the Government of India" (Adaptation of Indian Laws) Order, 1937.

2 Substituted for the word "Local Government" by the Government of India (Adaptation of Indian Laws) Order, 1937.

3 Substituted for the word "Gazette" by the Government of India (Adaptation of Indian Laws) Order, 1937.